STUDY OF THE MARINE ENVIRONMENT OF THE NORTHERN GULF OF CALIFORNIA

John R. Hendrickson
Biological Sciences Department
University of Arizona
Tucson, Arizona 85721

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16. Abstract

Results of studies of the oceanography of the northern Gulf of California (Mexico) are reported. A remote, instrumented buoy measuring and telemetering oceanographic data by ERTS-1 satellite was designed, constructed, deployed, and tested. Regular cruises by a research ship on a pattern of 47 oceanographic stations collected data which are analyzed and referenced to analysis of ERTS-1 satellite imagery. A thermal dynamic model of current patterns in the northern Gulf of California is proposed. Findings are examined in relation to the model.

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Preface

Objective: To develop baseline information for the purpose of evaluating the feasibility of monitoring seasonal changes in the northern Gulf of California by ERTS-1 satellite.

Scope of work: Regular ship cruises to acquire ground observations from 47 stations in the test site; construction and deployment of remote data oceanographic buoy transmitting ground observations to receiving stations by satellite relay; ERTS-1 imagery analysis, aided by ship-collected ground observations; coordination of international scientific cooperation with Mexican scientists participating in ground data collection and photo interpretation.

Conclusions:

1. Low-cost remote buoys as planned are feasible and extremely valuable adjuncts to working ships.
2. Baseline data for monitoring seasonal changes in the northern Gulf of California have now been established.
3. A predictive model of circulation patterns which has been formulated promises value in planning future oceanographic work in the area.
4. There is a lack of summer data for complete evaluation of the suggested circulation model.
5. The northern Gulf is not undergoing any conspicuous, long-term changes in salinity or temperature.

Summary of recommendations:

1. There should be a continuing program of development and use of low-cost,remote oceanographic data collection buoys such as developed in this program.
2. Buoys should have on-buoy recording apparatus in addition to satellite telemetry capability.
3. The biota of the northern Gulf should now be investigated on the bases of the physical oceanographic parameters described.
4. Detailed topographic and current mapping of the channel leading northward from Wagner Basin should be undertaken.
5. The turbid waters of the extreme northern Gulf should be investigated with hydrometer techniques to provide a better understanding of specific gravity phenomena.
6. There should be a special program of spectral radiometric readings of northern Gulf waters to enable calibration of multispectral imagery for depth sounding. These readings should be from low-flying aircraft of Mexican registry. The same flights should undertake studies to integrate information on specular flashes from surface waves.
7. Computer mapping of the northern Gulf from ERTS-1 MSS digital tapes should be carried out.

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ACKNOWLEDGEMENTS

The Principal Investigator wishes to express his sincere thanks to all the members of the formal working team whose names and areas of responsibility are listed in the last paragraph of the Introduction. They gave unstintingly of their time, energy and expertise throughout the period of the contract, and deserve abundant praise for work well done.

Marine Sciences Technician at the University of Arizona, Richard McCrory, while not listed as a formal team member, kept the oceanographic operations running smoothly and served as capable interpreter on almost every cruise. Mr. C. C. Tatum saw to it that our ship had a good radio, and that it worked. Sr. Antonio Delgado Amao, Port Captain of Puerto Peñasco, Sonora, Mexico was an unfailing source of support and sound advice. Sr. Javier Ramirez of El Golfo de Santa Clara, Sonora was a tower of strength on repeated occasions during work near the mouth of the Colorado River, and a wise, practical student of this unusual piece of the sea whose opinions we came to solicit at every available opportunity. Our scientific colleagues at the Universidad Autonoma de Baja California, led by Oceanologist Katsuo Nishikawa and Dr. Saul Alvarez Borrego, multiplied the productivity of our field activity and made cooperative work with them a real pleasure. In particular, we are indebted to advanced student Luis Arnulfo Galindo Bect for many aspects of special assistance. Mr. Robert Mangum, in addition to handling particular responsibilities in the electronic engineering of the remote buoy, volunteered yeoman service in many other fields, from solving electrical problems aboard ship to skilled underwater work with SCUBA.

Sue Sorstokke and Janna McIntosh created and managed computer programs with inspiration, dedication and -- most important -- good, dependable results. Pat Stout handled complex library problems, prepared accurate bibliographies, and typed endless pages of correspondence and manuscript. Mimi Owens capably handled secretarial and clerical work for the program until her skill as an illustrator was discovered; thereafter she did two people's work and did it well. Lupe Hendrickson produced accurate translations from Spanish as required, typed manuscript, performed skilled drafting, read proof with meticulous skill, and handled all manner of other useful tasks as required in aid of the program.

Lastly, a particular word of thanks is due to Richard Stonesifer, our Scientific Monitor. He handled a difficult job with skill, decision and diplomacy. When he said "no", he remained a friend and earned our deep respect.

Type III Final Report for Period 21 June, 1972 - 19 September, 1973

Project UN 603, STUDY OF THE MARINE ENVIRONMENT OF THE NORTHERN GULF OF CALIFORNIA

I. INTRODUCTION

The purpose of this investigation was to test the feasibility of ERTS-1 monitoring of seasonal variations in salinity, temperature, water clarity, current patterns, bottom configuration and primary productivity in the northern portion of the Gulf of California between $31^{\circ}11'$ and 32° N. latitude (Figure 1). The project was to include the design and testing of remote, instrumented buoys for measuring and telemetering certain oceanographic parameters to the ERTS-1 satellite, a program of surface observations by regular ship cruises on a set pattern of oceanographic stations, image analysis from high altitude overflights and from ERTS-1 imagery, and general correlation of all available data on the northern Gulf where this appeared to be meaningful. Development of strong cooperative activity with Mexican scientists and scientific institutions was identified as a major desideratum of the program.

The northern portion of the Gulf of California has for some time been a marine area of considerable interest to both Mexico and the United States, being an important fishing ground and area of accelerated shore development for the former and the marine debouchment of the great Colorado River drainage system of the latter. Previous oceanographic data collection has, however, been infrequent and sporadic; there has been a lack of information necessary to provide a sound basis for understanding the oceanography of this distinctive body of water.

The present study, in addition to testing the general feasibility of satellite monitoring techniques for oceanography, attempted to make a quantum jump in advancing basic understanding of the northern Gulf. By combining a moderate level of traditional oceanographic ship activity with the synoptic imagery and spectral sensing capability of the ERTS-1 satellite, we hoped to document and explain phenomena which would otherwise have required heavy investments in time, effort and funds before clarification was achieved. Due to a combination of reduced get-ready time and extended shipyard work after the contract was let, only 10 months of the contract period were available for cruises. Our request for extension of the contract to permit the planned 12-month period for data collection was not granted, thereby eroding ability to quantify seasonal data as intended.

This report summarizes our findings and offers a new conceptual model of the seasonal circulation patterns in the northern Gulf. This model, conceived by Co-Investigator Lepley, conforms well with observed phenomena and explains a number of situations which previously appeared to be anomalous.

Due to a Mexican Government policy decision after contract work was begun, high altitude overflights of the northern Gulf were not possible, and imagery analysis had to be confined to ERTS-1 imagery. In adapting to this circumstance, plans for testing the feasibility of monitoring primary productivity in the northern Gulf waters were dropped.

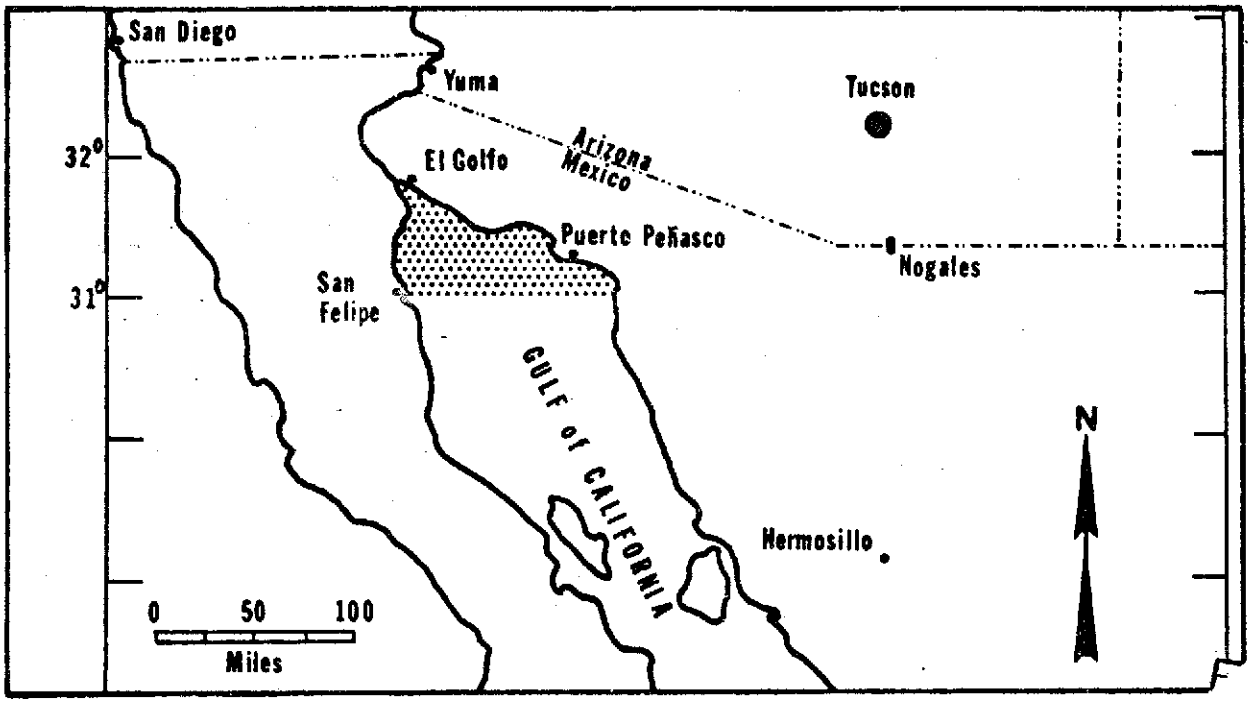

Figure 1. Study Site in Northern Gulf of California (stippled)

The unavailability of the hoped-for RBV imagery from ERTS-1 proved to be less of a handicap to our work than was expected -- largely because the MSS imagery obtained was of unexpectedly high quality and the 0.8-1.1 μ band of this material was extremely useful (this band would not have been available on the RBV material).

The work of the total program was divided into project portions according to special skills required. Responsibility for design, construction and deployment of the special buoys was undertaken by Professor Marvin D. Martin and graduate student Alan McFall of the Department of Aerospace and Mechanical Engineering of the University of Arizona, assisted by technician Steve Howard. Responsibility for the electronic engineering of special circuitry and adaptation of the NASA DCS packages for use on remote marine buoys was undertaken by Mr. John Sundberg, Electronics Engineer of the Biological Sciences Department of the University of Arizona, assisted by senior student Robert C. Mangum of the Department of Electrical Engineering and technician Michael Toepper. Co-Investigator Dr. Larry K. Lepley of Arid Lands Studies, University of Arizona, and graduate student Lt. (Mexican Navy) Gustavo Calderón undertook responsibility for imagery analysis and oceanographic interpretations of the imagery. The Principal Investigator and Co-Investigator Christine A. Flanagan (graduate student in biology, University of Arizona) undertook primary responsibility for all surface observations as well as for processing and analysis of data and general program coordination. Principal sections of the body of this report correspond with the indicated subdivisions of responsibility.

II. BUOY PLATFORM ENGINEERING

1. Design, Construction and Deployment of Platform

(Prof. M. D. Martin, Dept. Aero. & Mech. Eng., Univ. Ariz.)

A design was started in June 1972 for two remote, instrumented buoys to be capable of measuring and telemetering certain oceanographic parameters to the ERTS-1 satellite. The desired parameters were specified as: current direction and velocity, salinity, turbidity, dissolved oxygen, wind direction and velocity, and air and water temperatures. Commercially available instruments and associated electronic packages were to be used and the buoy was to be battery-powered with sufficient capacity to permit unattended operation for a period of one month. The telemetry, transmitter and antenna were supplied by NASA and adaptation to the instruments was to be accomplished by the UA Biological Sciences Electronic Shop.

a. Buoy Design and Construction

During preliminary studies of the basic buoy design, it was realized that in some areas of the northern Gulf where the current reached or exceeded 10 knots there would be danger of an anchored buoy submerging due to the vertical component of anchor cable tension. This would be especially true if location constraints limited the scope of the anchoring cable. It was therefore decided to design the buoys with hydrodynamic lift to augment the natural buoyancy and give added safety against this type of submergence. This decision, in conjunction with cost considerations, indicated the desirability of building a buoy consisting of a relatively thin shell of reinforced concrete surrounding a plastic foam core to provide the inherent buoyancy. Figure 2 shows a cross section of the design. The 45 degree bevel on each side represents a rudimentary air foil section which, when tethered at the indicated attachment point, produces an upward vertical component of force in a swift current. The buoy was made long enough in the direction transverse to the current to permit installation of sensors side by side, thus avoiding the interference between sensing elements which would have occurred had they been placed one behind the other.

The final dimensions chosen were those of a hollow rectangle 2.44m x 3.05m (8'x10') with a .610m x 1.83m (2'x6') center well in which the instrument packages and probes were located. The concrete was made .0635m (2-1/2") thick, the draft was .763m (30") and the freeboard .153m (6"). Overall displacement was about 3630 kg (8,000 pounds). In the center well, water-tight boxes were installed containing batteries, power supplies, amplifiers, the transmitter and timer and other electronic components. Water-immersed sensors were located between and below the boxes; the antenna and those sensors intended to measure properties of air were located on masts at the four corners of the buoy. The immersion of the packages of electronic equipment in water under the steel deck plate was designed to maintain cool operating temperatures by eliminating the

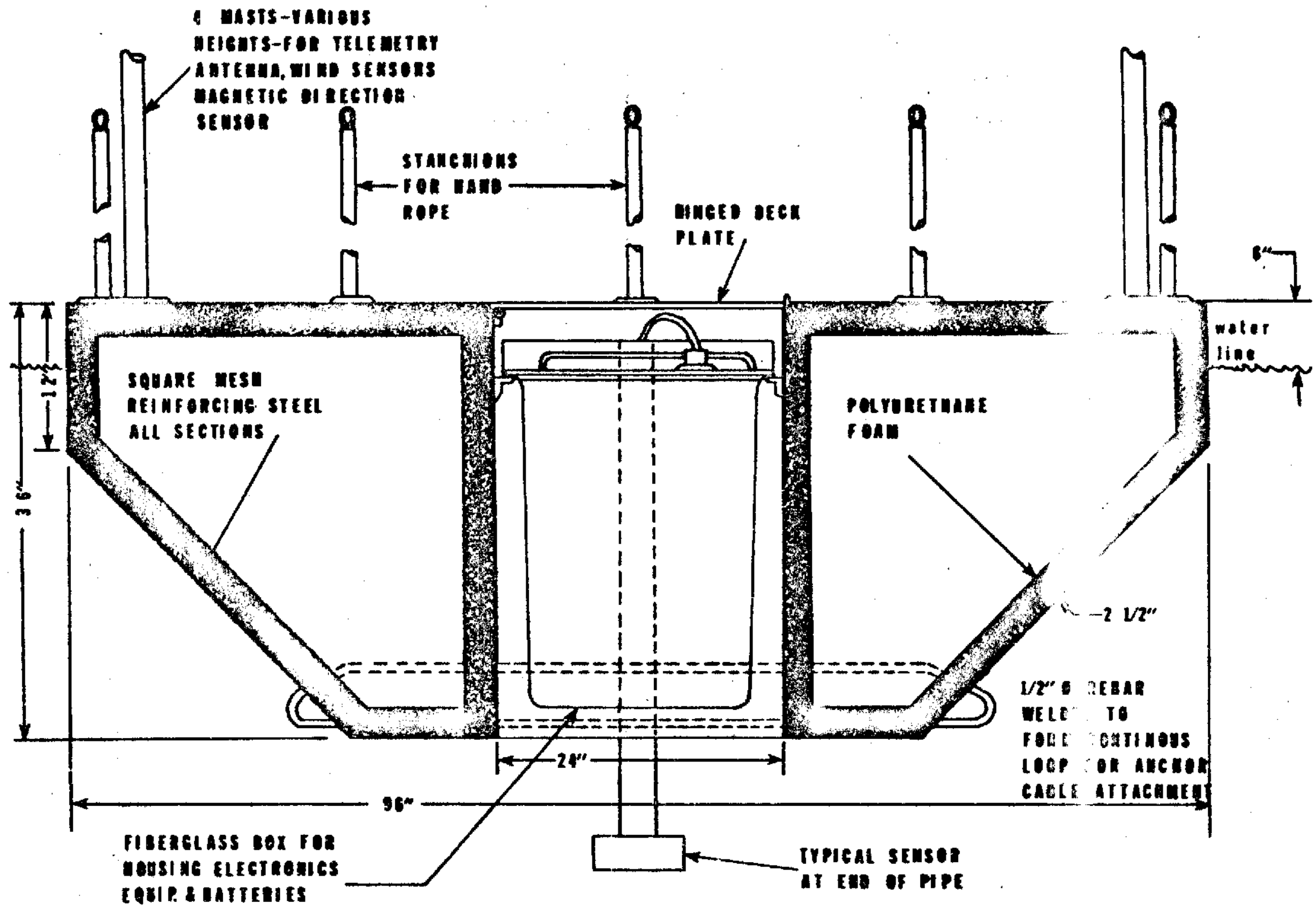

Figure 2. Section Through Buoy

heating due to solar radiation, thus keeping all components at the relatively constant temperature of the sea water. This location also was intended to provide considerable protection against accidental damage and vandalism. Standard highway obstruction flashing lights were wrapped in transparent plastic and secured to two of the masts to provide night visibility (Fig.3).

b. Buoy Deployment

The first buoy was poured in late September '72 and the forms stripped one week later. It was towed from the shipyard to an anchorage a few hundred yards off shore from the Puerto Peñasco Marine Science Laboratory and anchored without the electronic payload to test its stability and structural characteristics. While it was being towed to the anchorage, it was observed that the buoy assumed a positive angle of attack indicating that the underwater design produced the desired lift force. However, the towing speed was limited to about 4 knots because of the power available in the towing vessel; hence, this cannot be considered a definitive test of its performance at velocities of 10 knots and greater.

About two weeks after anchoring, a storm occurred which was accompanied by winds of greater than 30 knots for a period of several days. The buoy, as observed from shore, appeared reasonably stable in the accompanying high seas but the anchor dragged and the buoy eventually grounded on the beach about 1/4 mile east of the laboratory. It was determined that the design of the anchor which had been intended for use in the soft mud at the mouth of the Colorado River was unsuitable for the hard sand at the test location. A lack of sufficient scope in the anchor cable probably contributed to the failure of the anchor to hold. Attempts to refloat the stranded buoy were limited by the tidal cycles (tidal range in this part of the gulf exceeds 20'). A first attempt to refloat the buoy failed because it was too deeply embedded in the sand on the upper beach. A second attempt during the spring tide cycle of December 21-22, combined with prior excavations of the sand, was successful. It was reanchored using a redesigned system consisting of two commercial anchors rated for hard sand plus a generous length of heavy chain and a more generous scope of nylon cable. This anchor system has successfully withstood the forces on it from then until the present time (Fig. 4).

In grounding, the buoy passed over a section of rock reef in reaching the beach and the bottom pounded on the rocks, resulting in extensive damage to the concrete undersurface and exposing the reinforcing steel. The buoyancy was not significantly degraded (actually the loss of concrete increased the buoyancy by a small amount). The structure, however, was significantly weakened by the loss of the tie across the bottom between the two reinforcing bars which constituted the anchor attachment points.

Another severe storm occurred during March and the forces on the buoy were such as to tear out the reinforcing steel between the anchor attachment points. This resulted in the buoy's again breaking loose and grounding on the beach once more. This time the damage was so extensive as to be not reparable. A new buoy was poured during the week of April 2nd. The reinforcing steel at the anchor cable attachment point was doubled in this design and was laterally braced to better enable it to withstand wide loads. This buoy was anchored at the same location and with the same anchoring system as previously used. The

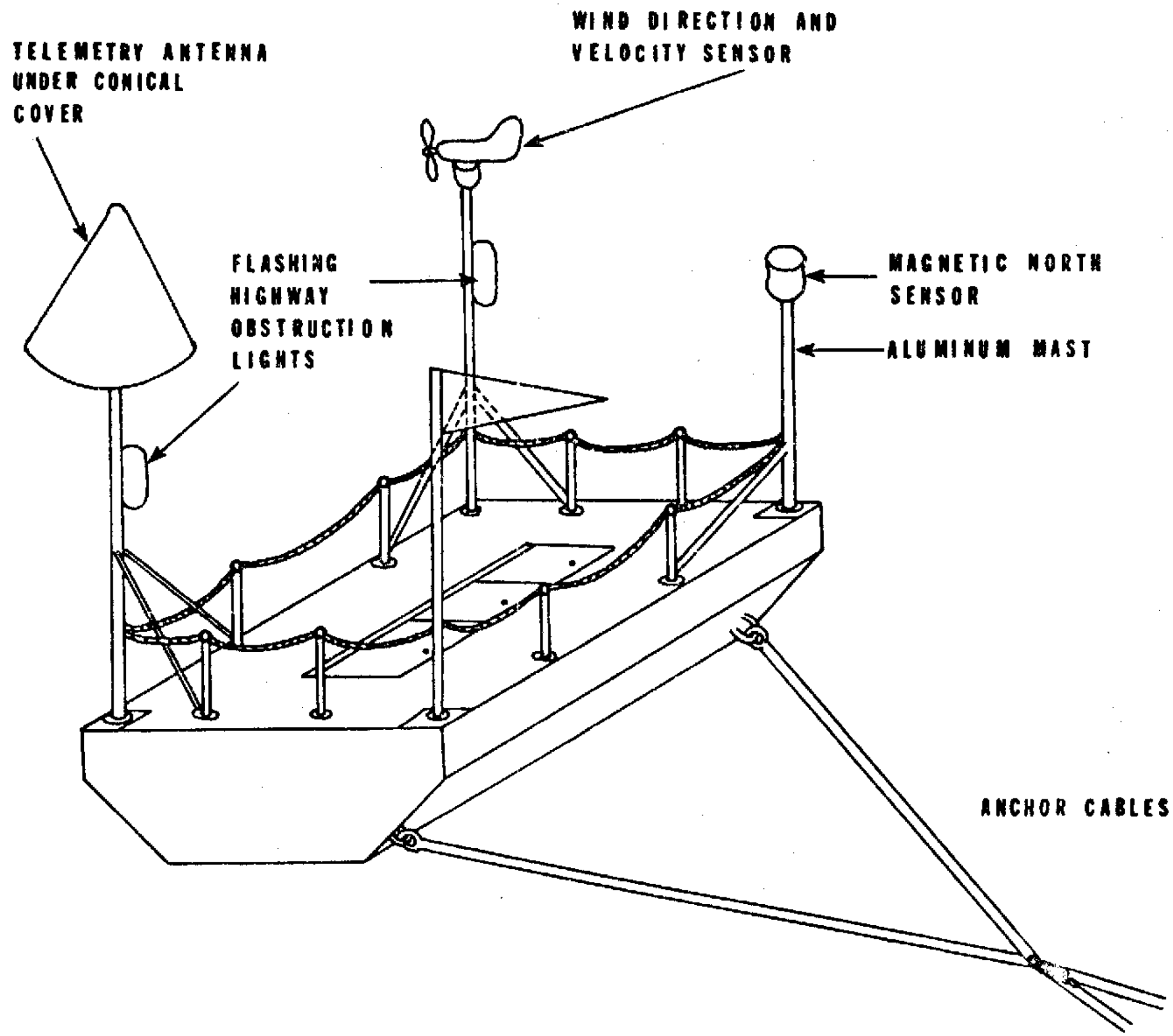

Figure 3. Buoy Superstructure and Tethering System

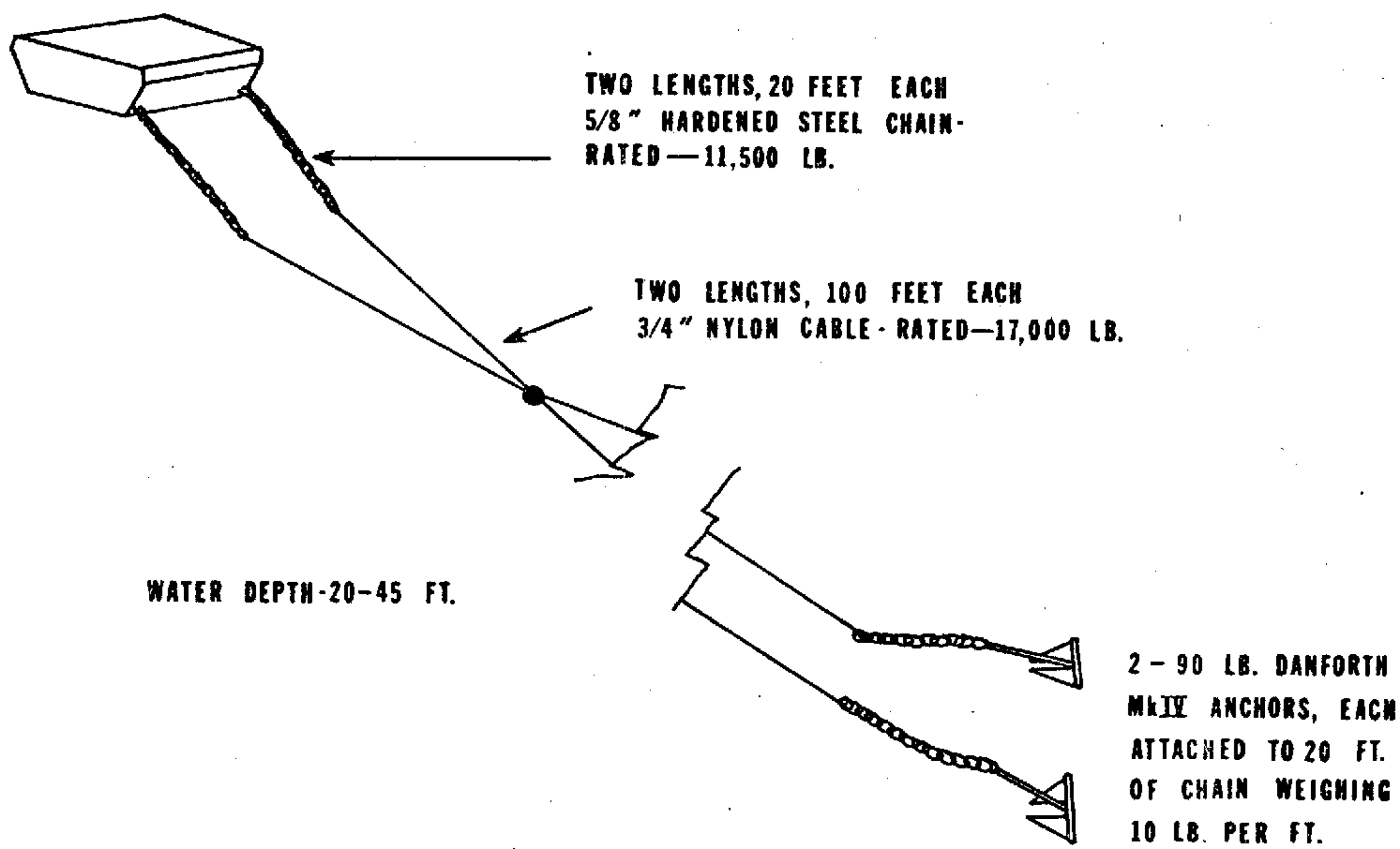

Figure 4. Final Anchorage Scheme for Buoy

buoy itself has successfully withstood an additional storm of even higher wind velocity than that before encountered. This storm did significant damage to the structure on the deck of the buoy, but no hull damage occurred. In particular, the antenna mast was broken and the antenna washed ashore and several of the 1-1/2" pipe flanges supporting the handrail stanchions were broken. These stanchions had been crudely tested on the finished buoy before deployment and were known to be capable of withstanding a bending moment of 400 ft.-lbs. without failure or significant deflection. A reasonable estimate of the drag necessary to cause them to break indicates that the water particle velocity must have been in excess of 16 1/2 knots:

Drag force, F, on stanchion is:

$$F = 1/2\ pv^2 S\ C_D$$

C_D = drag coeff. of long cylinder = 1.0

S = projected area facing current

$$S = \frac{2'' \times 30''}{144} = .417\ ft^2$$

p = mass density of seawater

$$p = \frac{64}{322} = 1.99\ slugs/ft^3$$

Assuming uniform velocity along length, F may be considered to be a concentrated force acting at the center of the 30 inch length. To produce the 400 ft-lb moment,

$$F = \frac{400 \times 12}{15} = 320\ lb.$$

Solving for v,

$$v = \left(\frac{2F}{pSC_D}\right)^{1/2} = \left(\frac{2 \times 320}{1.99 \times .417 \times 1.0}\right)^{1/2} = (770)^{1/2}$$

$$v = 27.8\ ft/sec$$

$$v = 16.5\ knots$$

Observers on the beach reported breakers estimated to be 3.5m (12') high coming across the deck of the buoy during the storm. It is clear that a structure to be mounted in this manner must be designed to take water velocities greatly in excess of those contemplated when the first buoy design was executed. It is now known that the local storms, called Chubascos, are exceptionally severe, occurring frequently in the upper Gulf during the spring and summer months. These storms, in combination with the shallow water at the chosen

anchorage, can result in a heavy surf and an environment far worse than that contemplated during the original design. The above deck structure has been redesigned and reinstalled but has not yet been called upon to withstand a severe storm.

The packaging of the electronics components introduced a serious unforeseen problem. The size of the well in the center of the buoy had been chosen before purchase of the commercial sensors and their associated amplifiers and power supplies. In fact, these components were not received and examined until November '72, long after the first buoy was completed. When they were finally received, it was realized that their physical size was much greater than had been planned for in the initial design period and that there was insufficient space to mount them as originally planned. It also became apparent that the power demands were such as to require three large truck batteries plus two 12-volt dry cell packs instead of the two small aircraft batteries originally contemplated. One of the units, in fact, required input power of 110 V 60 hertz and it was necessary to incorporate an inverter-transformer package to supply the power to this unit. The combination of the added power requirements and physical size made it necessary to package the electronic components in two large, specially designed fiberglas containers and to arrange the battery and inverter packages in a double-decked arrangement in order to accommodate all of the components in the available space.

Difficulty was also encountered in using the connectors which were procured to accomplish the necessary inter-connections from sensors and batteries to the electronic packages. It had been planned to purchase connectors designed to permit connection and disconnection underneath salt water for 12 volt circuits since it was recognized that, even in a moderate sea, waves would frequently submerge the deck of the buoy. In the interest of economy, however, less expensive connectors were obtained which were not as resistant to salt water immersion. As a consequence, there was considerable trouble with regard to corrosion and drain of battery energy. These connectors also turned out to be inadequate from the standpoint of their seals. The design contemplated pressurizing the containers with gas containing a freon tracer and the use of a halide leak detector to insure that no leaks existed before risking the electronic packages to salt water immersion. The connectors as procured had numerous leaks and it was necessary to perform a major redesign and refabrication of their attachment in order to satisfy the pressure integrity requirements placed on the packages. These requirements were strictly adhered to as insurance against salt-water-induced corrosion of the expensive electronic components contained in the boxes. Finally, a successful seal was obtained with the connectors. It should be noted that the locally designed gaskets sealing the lids to the boxes were satisfactory from the first and that the only leak trouble encountered was related to the electrical connectors. On assembly, another difficulty was encountered with the connectors. It was discovered after their receipt that 4" of extra length were required in line with the axis of the connector to permit it to be potted in a water-tight manner to the cable. These particular connectors had no provision for bringing off the cable at right angles to the connector axis. This unfortunate situation resulted in the total connector length being so great that it was impossible to close the deck plates completely and afford the planned protection to the electronic components. Upon deployment, it was necessary to fasten the deck plates in an open position. In future designs it is recommended that right angle connectors designed for underwater connection be a firm requirement.

The first installation of the electronic packages was accomplished in a moderate sea and most of the operations of assembly were performed under several inches of water. The motion of the buoy was lively during this period and the installation crew suffered from a moderate amount of seasickness. At the initial assembly, one battery connection was inadvertently left off, resulting in an added battery load due to the conductivity of salt water. This caused the battery voltage to drop to an unacceptable level after two days of operation. The entire system performed satisfactorily for the 2-day period. At about the end of this deployment period there also occurred the most severe storm encountered during the year, referred to above, in which the antenna and antenna mast were broken off and washed ashore. Replacement of the antenna, including stronger mast bracing, recharging of the batteries, and proper connections of the cabling, resulted in successful operation of the unit for approximately two weeks. Figure 5 shows the operating buoy at sea. Operation was terminated at the end of June 1973 due to expiration of the contract.

Due to setbacks in timing caused by delays in delivery of equipment, storm damage, etc., the first buoy was successfully tested at such a late date in the contract period that construction of another buoy would have been justified only if the contract were extended. This did not take place and, by agreement with NASA headquarters, it was not built.

Conclusions and recommendations from this portion of the work are presented in the general sections at the end of this report (see pp. 98 and 101).

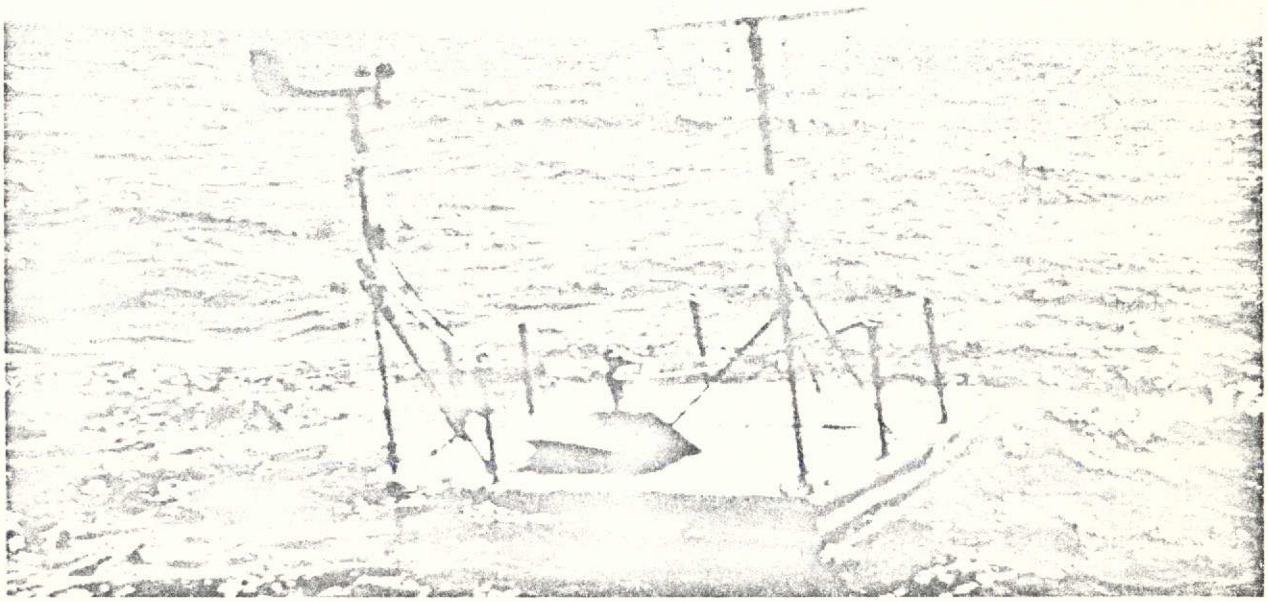

Figure 5. Instrument Buoy at Sea

2. Buoy Electronic Systems Engineering

(Mr. John Sundberg, Biol. Sci. Electronics Shop, Univ. Ariz.)

The electronics engineering tasks associated with the data buoy were broken down into six areas: 1) Parameter sensor review, acquisition, adaptation and evaluation; 2) Signal conditioning circuitry design, testing and evaluation; 3) Slow speed multiplex circuit design, testing and evaluation; 4) Period timer and synchronizer design, testing and evaluation; 5) Power supply design and evaluation; 6) Interconnection of the above including cabling between electronic units, assessment of environmental impact of salt water on connectors, and packaging of designed and assembled electronics. As a result of severe man-power shortage, these tasks had to be performed in a series manner rather than the more expedient parallel one which would have been desirable, given sufficient personnel. In addition, discovery of unexpected discrepancies between DCP manual and apparatus, and of deficiencies in DCP and test set design, caused delays which were magnified by the series approach.

a. Parameter Sensor Review, Acquisition, Adaptation and Evaluation

The following parameters were identified as desirable for measurement: salinity, water temperature, conductivity, current velocity, current direction, turbidity, dissolved oxygen, air temperature, wind velocity, and wind direction.

An exhaustive search of available oceanographic instrumentation was conducted to determine the most appropriate measurement device for each of the desired parameters. Selection of instrument type and manufacturer was dependent upon the following project requirements and guidelines: 1)capability of unattended, reliable, repetitive measurements for a period of up to 40 days; 2)capability of measurements within the desired range and of the desired precision; 3) low susceptibility to fouling by suspended particulate matter and marine organisms; 4) demonstrable previous success of apparatus under severe field conditions comparable to those of this project; 5) cost, to allow system acquisition within stipulated budget limits; 6) delivery time to meet project schedule 7) forecast of suppliers' ability to service, modify, and consult on use of their product; 8) signal conditioning requirements for interface with telemetry package; 9) power requirements.

Displayed in Table 1 is a listing of the parameters and associated specifications for which the buoys were to be instrumented. Table 2 shows instruments chosen.

It was decided to measure conductivity and temperature on a single inductive instrument, using computer software to convert temperature and conductivity to salinity as well as tabulating the temperature data separately. The most accurate method of measuring conductivity is to induce a field, using AC, into the sample volume of water. The current flowing in another loop will be proportional to the conductivity and with proper electronic techniques can be converted to a DC voltage which is applied to the DCP. Interocean Systems was found to have a rugged probe which has no moving or exposed parts and their Model 513 was selected to measure temperature and conductivity of the water.

Table 1

Remote Buoys: Measurement Parameters and Specifications

	Oceanographic Parameter	Range	Accuracy	Comments
1.	Water Temperature, 1m depth	11° - 35° C	$\pm$ 0.2° C	Depending upon where buoy is anchored, may want 3m and 5m depths also.
2.	Salinity, 1m depth	33 - 39°/oo	$\pm$ 0.1°/oo	....
3.	Conductivity, 1m depth	0 - 65 mmhos	$\pm$ 0.05 mmhos	Not primary measurement; for correlation with temp. to calculate salinity.
4.	Current velocity, 1m depth	0 - 10 knots	$\pm$ 0.2 knots	Accuracy figure may be negotiable.
5.	Current direction, 1m depth	360° revolution	$\pm$ 5°	....
6.	Turbidity, 1m depth	0 - 25 ft. visibility	?	Accuracy constraint wholly dependent upon sensor specs.
7.	Dissolved oxygen, 1m depth	0 - 8 ml/l	$\pm$ 0.2 ml/l	Accuracy constraint indicated is desired, but must remain dependent upon sensor specs.
8.	Air temperature, 1 - 2 m above sea surface	-2 to +45° C	$\pm$ 0.2° C	Exact height above sea surface dependent upon engineering factors.
9.	Wind direction, 1 - 2 m above sea surface	360° revolution	$\pm$ 5°	Exact height above sea surface dependent upon engineering factors.
10.	Wind velocity, 1 - 2 m above sea surface	0 - 70 knots	$\pm$ 2.5 knots	Exact height above sea surface dependent upon engineering factors.

Table 2

Remote Buoys: Sensing Instrumentation

Parameter	Manufacturer	Model
Temperature (both water and air)*	Yellow Springs Instrument	Model 701; Model 705
Salinity (via temp. + conductivity)	Interocean Systems	Model 513
Current (velocity and direction)	Marsh-McBirney	Model 711
Turbidity	Monitor Technology	Model 2-350
Dissolved Oxygen	Weston and Stack	Model 3000-1-A with A40 probe and A25 agitator
Wind Direction and Velocity	Bendix	Model 120
Compass Direction (for correcting both current and wind directional readings to true compass readings)	Humphrey	North-seeking device NS 04-0301-1

* In addition to the Interocean Systems probe measuring temperature and conductivity for salinity calculations plus direct temperature readout, a redundant temperature probe was used in the water.

Yellow Springs Instrument thermolinear thermistors were used to measure air temperatures and water temperatures (redundant instrumentation for cross-checking the Interocean probe). These devices use several thermistors in a composite to obtain a linear voltage output with temperature.

Measurements of current velocity and direction had to be made with a static device because of high levels of suspended sediment in the water where the buoy was placed. The moving parts of impeller devices would become fouled in a short time. The Marsh-McBirney sensor selected uses an electromagnetic induction principle and produces two orthogonal components of water flow perpendicular to the longitudinal axis of the probe. Computer software converts this data, plus information from a north-seeking device, into true direction and speed.

The north-seeking device uses a magnetic compass attached to a potentiometer. The output is proportional to the resistance, which in turn is a function of direction referenced to magnetic north.

Turbidity measurements present a special challenge in the environment to be studied, where Secchi disk visibility may vary from 1/2 inch to 35+ feet. A unit is needed which is capable of operating when fouling is present and which is capable of measuring very high particle levels. The Monitek unit selected uses two light sources and a forward-scatter technique. It compensates for ambient light and for lens obscuration up to 50%.

Dissolved oxygen measurements are particularly difficult to make with unattended apparatus, and the extreme marine environment concerned here compounds the problems. The Weston and Stack model selected has been proven in severe environments. Built into the probe is an agitator which can be adjusted to wipe the membrane if fouling becomes a problem.

Wind velocity was measured by an impeller instrument with a good history of use on oceanic buoys. A DC generator was employed along with a synchro output for direction. This direction was referenced, as for current direction, to the north-seeking device and computer software provided true direction.

All sensors appeared to operate satisfactorily during the two week operational period at sea, with the exception of the Yellow Springs Instrument Co. thermolinear thermistors which were incorporated in the buoy system as redundant instrumentation for cross-checking the Interocean probe. The satellite-relayed data from these thermistors was completely off-scale on the high side. Since these thermistors checked out well during simulated environment tests in the laboratory, it is assumed that the faulty transmission from the deployed buoy was due to some unidentified artifact such as a circuit break, most probably in a connector cable damaged at sea.

b. <u>Signal Conditioning Circuitry</u>

Burr Brown 3500 A operational amplifiers formed the nuclei of the analog channel signal conditioning. They are improved versions of the 741 type

operational amplifier and it was felt that, since slew rate, low input bias current and most other critical parameters of the operational amplifiers were not very stringent, these amplifiers should suffice. They have excellent minimal drift characteristics, which was the basic reason for selecting the 3500 type. Various restive networks were needed in conjunction with the operational amplifier circuits for matching the circuits of the potentiometric North Seeker and thermistor composites, and for dividing down those outputs which were higher than 5 volts so that the operational amplifier could be used to give 0-5V output for the range of each sensor. Test circuits were designed and put into a prototype unit for testing of drift due to temperature and time. They provided excellent performance.

Since the wind direction sensor was a synchro-transmitter, a synchro-to-DC converter had to be found and this made necessary a sine wave inverter in the power section. This type of problem came up repeatedly, as most of the equipment available is designed to run off of 60 hz mains. AC operation could probably have been eliminated altogether, but the lead time for redesign of these circuits made this impossible.

c. Slow Speed Multiplex Circuit

As the number of parameters to be measured exceeded eight, it was necessary to develop a system to increase the capabilities of the DCP. Since the location of the buoys is well situated for rather long acquisition times to Goldstone, it was decided to decrease the DCP timing period to 90 seconds rather than the standard 180. Then, by switching between two sets of eight sensors each, the capability could be increased to 16.

It was decided to use the data gate signal to trigger a Flip Flop which in turn would activate relays and select the proper channels. Our first problem occurred when it was found that no data gate was present on the analog plug of any of the three DCP's we had. The manual with its wiring diagram showed this signal to be available at the analog plug. It was available at the test plug, however. Now, since no power is applied to the hex inverter which supplies the data gate except during the approximately 80 ms. of the power up-time, noise was present on the line and the output of the data gate had to be clamped to 5V (keeping in mind the current sink capabilities of the data gate inverter) to make it function as a proper logic circuit. In our opinion, it would have been desirable to have designed the DCP to keep this circuit energized, even if low power logic had to be used.

After completing the first prototype of the Multiplex, it was still being toggled at some point in the middle of the power-on cycle. This meant the circuit toggled when the data gate first appeared and then again half way through the power-on cycle. A storage scope was used to determine exactly where the problem was occurring and it was found that a positive going spike appeared when the transmitter was pulsed. A regulated supply of enough current capability to provide for the peak power was being used, demonstrating that the regulation within the DCP must not be adequate. A circuit was designed using a NE555 IC timer which is energized at the appearance of the data gate. The output of this circuit provides a positive level to the Flip Flop (edge triggered) to prevent any further transients from affecting it.

Since it is unaffected by any pulses during its timing cycle, which was set for ten seconds, the Multiplex is held in one position until after the data gate is unpowered.

The above problem consumed some time because a storage scope was initially unavailable and, until we used one, we did not know that the DCP was the root of the problem.

The Multiplex uses solid state relays which eliminate contact bounce and coil kickback, and give excellent time response. This technique of locking out the input for a pre-determined time to suppress noise was not noted in a search of the literature, but it may well have been used previously by other workers.

The Multiplex circuit was bench-tested over a 72-hour period using a DCP and gave excellent results. It was also tested in a roof-top installation at the University and data were received for a ten-day period.

We have not studied the overall DCS system in depth, but it seems possible that timing periods of even less than 90 seconds could be used to obtain still more data; however, this could result in interference at some sites in the circuitry. If electronically feasible, broadening of the data base in this manner could be advantageous to some users.

d. Period Timer and Synchronizer Design, Testing and Evaluation

The design philosophy for the circuitry of this device changed several times due to the designers' lack of knowledge of orbital mechanics.

The need for the timer arose because of limitations on the amount of electrical power available on the buoy. Some method was needed to turn sensor and electronic devices off when the satellite was not in view of receiving sites.

The first design plan was to turn on power when the satellite crossed the latitude of Goldstone (actually, ten minutes before, then hold power on for 20 minutes). This was to be done every orbit using a timer having the period of the satellite as its base. It was originally thought that this would give transmissions on all usable orbits day and night. The time on would then be about 280 minutes per day. This circuit was built and tested and did indeed perform its electronic function as intended. However, further thought on the subject made the designers realize that only the AM orbits would be usable, as the desired PM orbits are ascending ones and a timer synchronized to the satellite descending over the buoy would not give the desired results.

Some thought was given to having separate AM and PM timers to permit activation on each ascending and descending orbit, but the power-on demands proved too great. The design was for a complex timer to turn on for the first usable AM orbit, remain on for 20 minutes, turn off until the next orbit, and repeat this cycle for three orbits AM. Power would be off until the PM orbits, when the cycle would repeat. For day N + 1, the turn-on time would change by approx-

imately six seconds and after 18 days, everything would reset. It was decided that this circuitry was more complex than the whole buoy, and it was therefore discarded.

The final solution, which fortunately was rather straightforward, was to use a period timer and gate its output with a comparitor whose output came from a GMT-based 24-hour clock circuit. Two outputs were available from the clock circuit: 0900-1200 and 2100-2400 local time. This insured the use of power only for those orbits which could be used. No day-to-day changes had to be programmed.

The timer circuits used a Motorola temperature-compensated crystal oscillator with a stability of better than one part in 10^6 per year over a temperature range of 0^o-5^oC and a power consumption of only 250 mw. The divider circuits were comprised of low power 7400 logic and the output of the solid state twenty minute timer activated a solid state relay capable of switching the entire load.

e. Power Supply Design and Evaluation

As mentioned previously, 115V 60 hz power was chosen for operation of some of the sensors, as DC option power supplies would have taken too long to obtain. An added requirement was the need for sine wave excitation for the synchro in the wind direction sensor. A sine wave solid state inverter was decided upon for all AC needs.

The DC-DC converters needed for the remainder of the electronics were solid state modular types obtainable as off-the-shelf items.

f. Interconnection and Antenna Tests

A very difficult problem to solve was the connector selection for the interconnection of the battery boxes and electronics boxes. Since it was not necessary to disconnect or connect the cables underwater, and since the connectors would not be used at any appreciable depth, specialized underwater connectors were felt to be too expensive. In addition, these were deemed inconveniently bulky. Since most connectors use aluminum for the metal parts, great care had to be taken to obtain ones having a finish capable of withstanding salt water immersion. Bendix QWLD series connectors were specified; it was felt that they are adequate for the environment, yet do not have superfluous features. (See, however, mechanical engineers' comments, p. 9.)

No facility existed in the Biological Sciences Department for printed circuit board design or fabrication, but it was felt that this type of circuit construction was necessary for a professional product. The art work and actual fabrication of the boards were done locally in cooperation with the design engineers as a purchased service.

Some delays were encountered due to problem areas with the GFE items (Government Furnished Equipment). The test procedure as written in the manual was inaccurate and it seems we were the first and possibly the only user to call the attention of General Electric Corporation (the fabricators) to this defect.

The voltage in the field test set was too high and until late in the program no modification kit or instructions for managing the problem were available from GE. This involved a small design change, but in the meantime the test set could not be depended upon to give accurate checkcuts, as the logic buss voltage exceeded the specifications for the logic being used.

An antenna test was performed at sea prior to finalizing the timer circuit, as some concern was felt over the possibility that wave motion at sea would cause the antenna angle of radiation to change, resulting in loss of transmissions; since a Multiplex is used, this could cause loss of half of the data. The DCP was kept on the service boat, the ADVENIYR, and a coaxial transmission line was attached to the antenna mounted on the buoy. All transmissions were received in sequence on January 13, 1973 at approximately 1719-1734 GMT with a buoy/antenna motion up to 30°.

g. Deployment and Operation

The system was assembled in its final form at the University and transmissions were sent from the roof of the Biological Sciences building. The physical parameters to be measured were duplicated as closely as possible to simulate a working environment. Data were successfully received and the circuits were sealed for installation on the buoy.

Due to mechanical problems in launching and setting up the buoy, adequate communication was not established between the electronics and mechanical engineers during the first deployment effort. As a result, protection of the connectors was overlooked and they became exposed to salt water before they could be connected. This necessitated removal of the electronics boxes and a thorough cleaning process back in Tucson.

On the second attempt, the personnel installing the boxes and working the electrical connectors were briefed on the proper procedures and, while the installation process was difficult because of sea conditions, no salt water contamination of connectors occurred.

Data were received from all sensors deployed and both AM and PM transmissions were accomplished, showing that the timing circuits were operating in a satisfactory manner. Transmissions on one channel which monitored battery voltage demonstrated that power consumption was as calculated. The transmissions continued for about two weeks when they suddenly stopped. At the time of the last-received transmission, battery voltage was still high. When the buoy was visited, it was found that one of the compartment lids on the buoy had come loose and severed the antenna cable.

Conclusions and recommendations from this portion of the work are presented in the general section at the end of this report (see pp. 98 and 101). Figure 6 is a block diagram of the buoy electronic system as deployed.

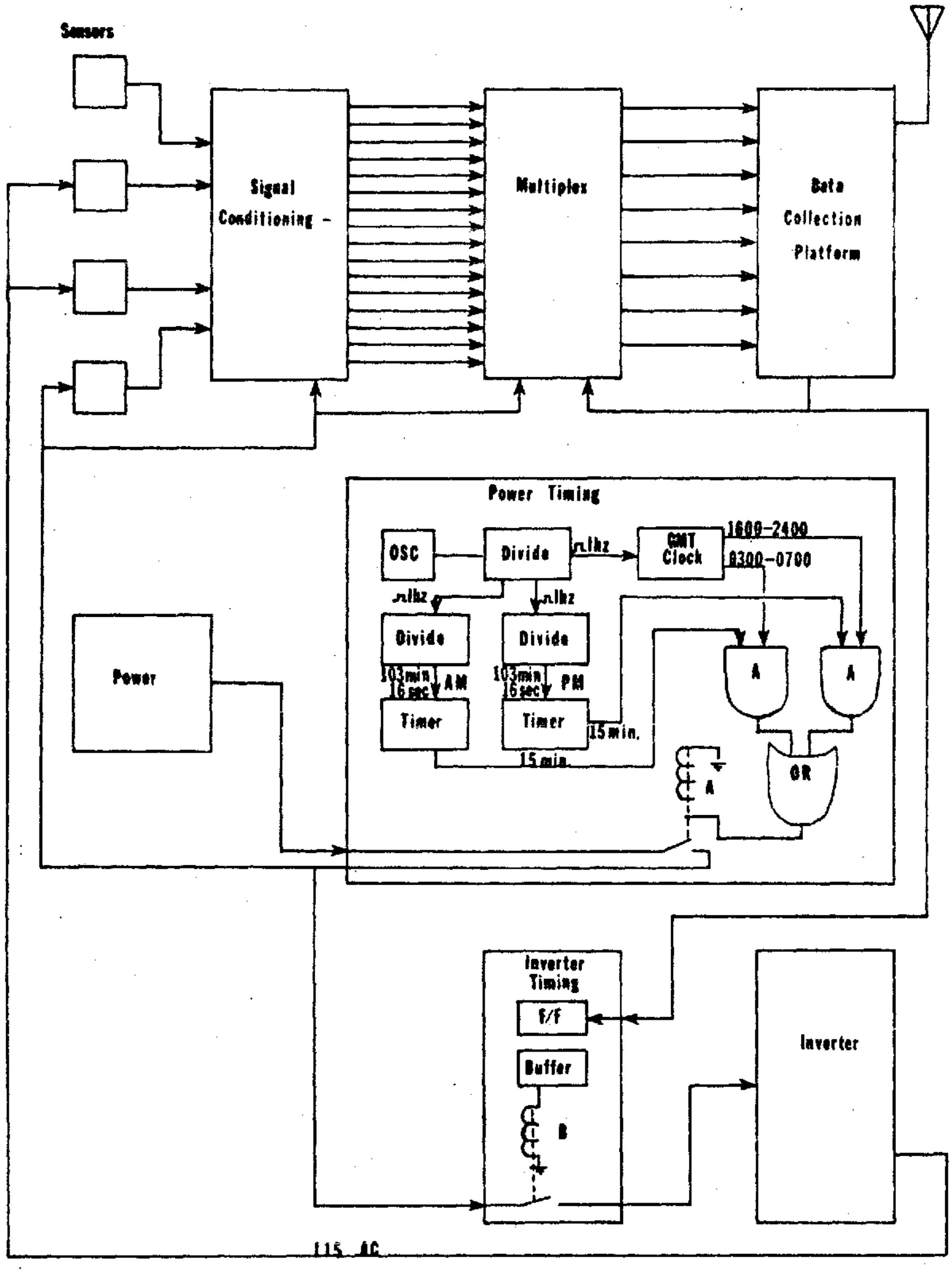

Figure 6. Buoy Electronic System - Block Diagram

III. SURFACE OBSERVATIONS

(J. R. Hendrickson and C. A. Flanagan, Dept. Biol. Sci., Univ. Ariz.)

1. Land Station, Instrumentation and Methods

The land station contributing data for this report is the Universidad de Sonora - University of Arizona Cooperative Marine Station located just outside the town of Puerto Peñasco, Sonora, Mexico (Fig. 1). Meteorological data have been collected at this site since 1963; Green (1969) summarizes the earlier data, and reference is made to these records in section III-6 of this report. Since December, 1970 regular daily observations have been recorded by a single, experienced Mexican technician following a specified routine described below.[1] While based upon minimal instrumentation, the long-term continuity and dependability of this system has produced a collection of data with confidence levels superior to data collections produced under similar circumstances with more complex instrumentation, but with variable maintenance and record-keeping.

Each morning at 9:00 A.M. the first of two daily weather observations is made. Wind direction is recorded according to the 8 standard compass points. Minimum temperature (for that day) and maximum temperature (for the preceding day) are recorded from a minimum-maximum thermometer housed in a standard meteorological instrument shelter. The observer then walks to the sea shore directly in front of the marine laboratory where there is uninterrupted wave wash from the open sea, wades out a short distance into the water, and throws a pail on a 20 foot rope straight out to sea. The temperature of the water retrieved in this pail is recorded as surface sea temperature. Finally, sea state and general weather conditions for that hour of the day are recorded as shown in Table 3. At 4:00 P.M. each day, the afternoon wind direction is noted and a record is made of the number of revolutions on the recording anemometer since the previous day's reading (total air movement during the 24 hr. period).

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1. The long and eminently faithful service of Sr. Ramón Durazo, resident technician at the Univ. de Sonora - Univ. of Arizona Marine Station, is here gratefully acknowledged. His understanding of requirements and devotion to accuracy and constancy made possible important collections of information which would have otherwise been impossible to obtain.

Table 3

Meteorological Observations at Puerto Peñasco Marine Station, Dec., 1970 to Present

0900 hrs., daily	Minimum Air Temp., °C. (for computer purposes, assumed to be same-day temperature). Maximum Air Temp., °C. (for computer purposes, assumed to be preceding-day temperature). Morning Wind Direction (on 8-point compass) Sea Temperature, °C. (surface, near-shore) Sea State (see category code, below) General Weather Observations (see category code, below)
1600 hrs., daily	Afternoon Wind Direction (on 8-point compass) Total Air Movement Over Previous 24 hrs. (recording anemometer reading)

Sea State Categories	NODC[1] Code
Flat Calm	1
Small Waves	2
Medium Waves	3
Large Waves	4
Very Large Waves (Rough Seas)	5
Storm Conditions, Very Rough Seas	6
Hurricane Conditions (Most Extreme)	7

General Weather Observations	NODC Code
Clear	0
Medium Cloudy	1
Cloudy	2
Very Cloudy	4
Drizzle	5
Rain	6
Mist	4
Dust Haze	3
Hail	9
Snow	7

1. National Oceanographic Data Center, Washington, D. C.

2. Ship Platform, Instrumentation and Methods

By agreement with the Universidad de Sonora, this program obtained the sole use of their research vessel "ADVENTYR" for the period of the NASA contract. The "ADVENTYR" is a 46 foot, steel-hulled, diesel-powered vessel of 17.8 gross tons, especially constructed with side keels to facilitate beaching in the extreme tidal region of the northern Gulf of California. The ship was overhauled and remodelled as necessary for contract work; a full-time Mexican captain, a crewman/cook, and a port watchman were employed for the period of the contract. These costs were partially met through National Science Foundation Grant GB34675 ("Research Ship Support") in supplementation of NASA contract funds.

The "ADVENTYR" was equipped with an OMEGA Model 1100 Navigational Receiver and with a Raytheon Model DE 735A Recording Fathometer. This instrumentation provided an accuracy for repetitive station location which compared favorably with ERTS-1 resolution. The U. S. Coast Guard decision to shut down the Hawaiian station of the OMEGA network in February, 1973, without waiting for completion of the Japanese station which could replace it for our purposes, eliminated the accuracy of the OMEGA navigation system from that date forward. Fortunately, the majority of our oceanographic stations in the northern Gulf have land visible in at least one quarter; by the time the OMEGA navigation system became useless, familiarity with the station patterns, sea conditions, and land reference points made possible the reasonably accurate location of stations by dead reckoning.

Conductivity and temperature were measured with an Interocean Model 513 probe with Model 514 analog deck readout showing conversions to salinity as well as the two measured parameters. Measurements were routinely made at each station at the surface and at depths of 1, 5, 10, 20, and 25 meters as depth of water permitted.

Turbidity was measured with a Secchi disk, with units of depth-visibility expressed in feet to conform with the main body of existing data for this area. On the later cruises of the contract period, ERTS-matched reflectance spectra were collected using an Exotech four-channel radiometer. Penetrance of down-welling light was measured with a submarine photometer matched with a deck cell (Fred Schueler, Waltham, Mass.), the submarine cell being lowered to extinction readings.

Plans to make systematic current speed measurements on station from the R/V "ADVENTYR" had to be dropped. It proved impossible to achieve anchoring ability over the great depth ranges concerned, and in the northernmost stations the special problems of anchoring in extreme currents over a soft bottom in restricted channel situations proved to be inadvisable. In addition, earlier attempts to use the instrument on board ship encountered severe problems of electronic noise which could have been overcome only with difficulty.

The ship was fitted with a Dwyer Pitot Tube Wind Speed Indicator. Wet and dry bulb temperatures were taken with a Taylor Whirling Hygrometer. Barometric pressure readings were taken from the ship's aneroid barometer.

Cloud cover % and cloud type were determined according to guidelines printed in the ESSA Cloud Chart (ESSA/P1680002) and according to the United States Naval Oceanographic Office publication Instruction Manual for Obtaining Oceanographic Data (1968). The latter manual was also the source followed in making sea and swell observations, weather observations, and in use of the on-board instruments and equipment.

At each station, several 10 meter vertical hauls were made with a ½ meter diameter, #6 mesh plankton net where depth and current permitted. Where the water on station was too shallow to permit a 10 meter vertical haul, a haul through approximately 10 meters was made by manually casting the net out from the ship. Where strong currents prevented vertical hauls despite heavy weighting of the net bucket, the best estimate of a 10 meter water column was strained and the haul was noted as "oblique"; in every case, wire angle was noted.

In addition to plankton net samples for macro-zooplankton, 500 c.c. samples of surface water were treated with Lugol's iodine and preserved for microphytoplankton studies.

Personnel of the Universidad Autónoma de Baja California Institute of Oceanology participated in a number of cruises during the contract period. In addition to assisting with work such as described above, they measured temperature with traditional oceanographic reversing thermometers and took water samples with Van Doren Samplers and Nansen Bottles. Determinations of pH (Orion Model 407 pH Meter) and dissolved oxygen (Winkler method) were made on board; laboratory determinations were made of alkalinity (Orion digital Model 801 Alkalinometer) and of salinity (Bisset-Berman Laboratory Salinometer), and frozen water samples were preserved for laboratory analysis of silicates, phosphates, nitrates and nitrites (Coleman-Hitachi Model 139 Spectrophotometer).

Figures 7 & 8 show photos of the ship and some of the scientific equipment used.

Analyses of the plankton samples and of the Universidad de Baja California data will continue for some time to come, and are not included in this report.

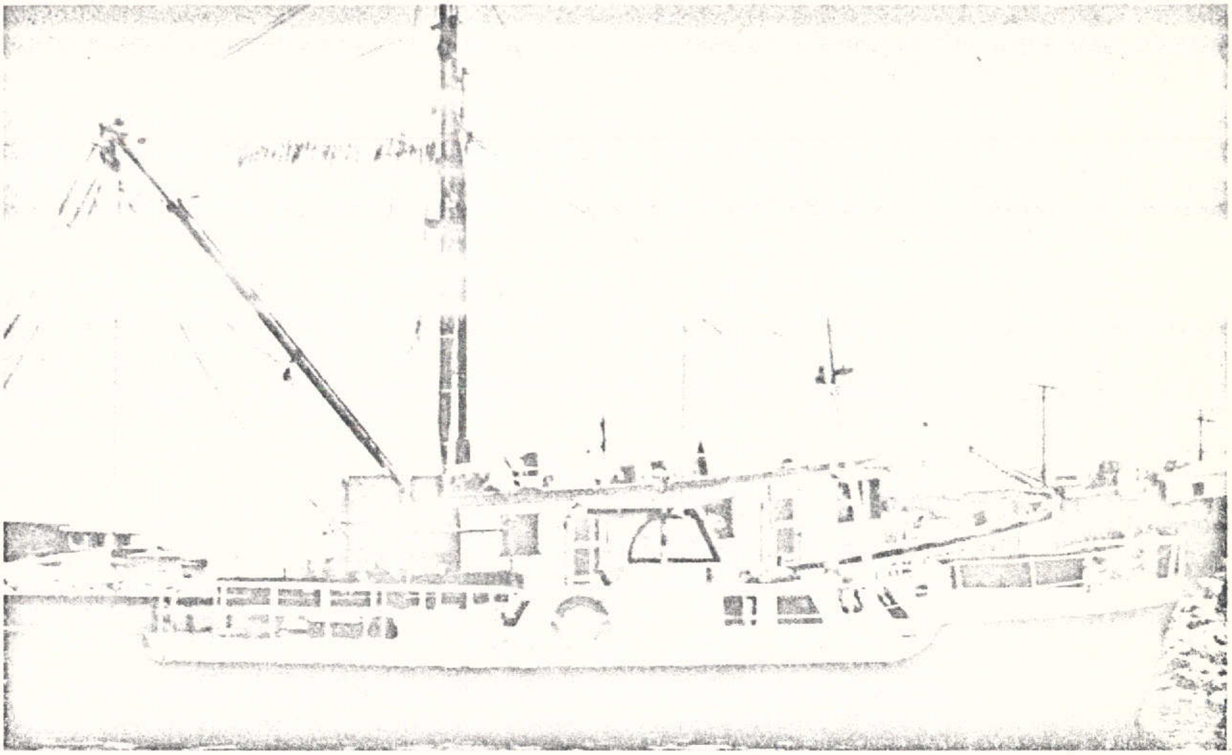


Figure 7. R/V "ADVENTYR" in Port at Puerto Peñasco, Sonora, Mexico.

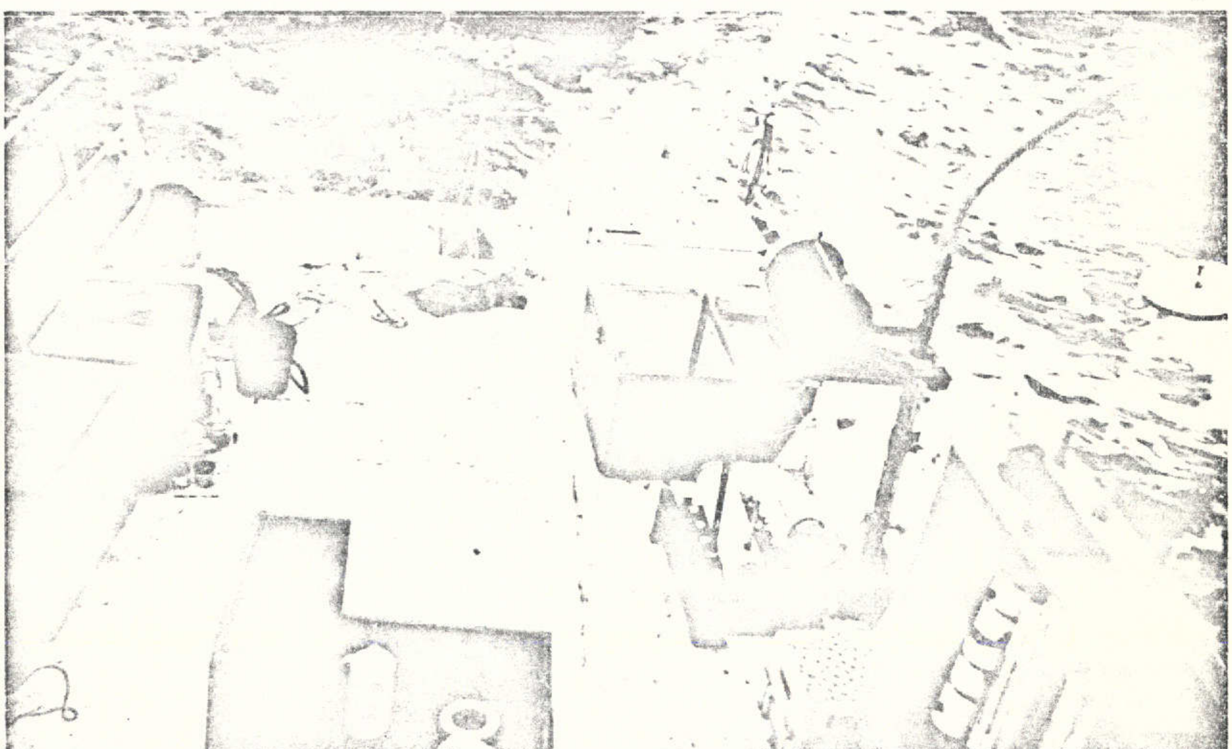


Figure 8. Deck of the R/V "ADVENTYR" Showing Distribution of the Scientific Gear on a Cruise.

3. Marine Data Collection Stations

Figure 9 shows the 47 standard oceanographic stations which were planned as sampling sites in this program, and Table 4 gives the coordinates of each station. The station grid pattern was set up on a spacing interval of approximately 10 nautical miles, with adaptations for shore line irregularities and points of special interest. One complete rank of stations was established at approximately 31° north latitude to provide against errors of interpretation at the southern margin of the test site. Station A4 proved to be too shallow for meaningful inclusion in the system (available only during about 15% of the tidal cycle); Station D9 was added to provide improved coordination with the studies carried out by the Universidad de Baja California personnel who participated strongly in the oceanographic work (see III-4).

All stations were visited to the extent that weather conditions and ship function permitted within the time periods available for each cruise. While severe weather was commonly a major problem preventing complete coverage of all stations, and ship dysfunction forced decisions to abort on at least three cruises, a reasonably good coverage of the study site was possible for the 10 month period of oceanographic work possible within the time limits of the contract.

Cruises were timed, insofar as possible, to include dates of ERTS-1 imagery passes over the study site. Table 5 shows cruises made and numbers of stations sampled in relation to the calendar year and ERTS-1 imagery orbit dates. Maps of the actual cruise routes for each month are presented in section III-7.

Samples of standard data collection forms employed for the oceanographic work are provided in Appendix A.

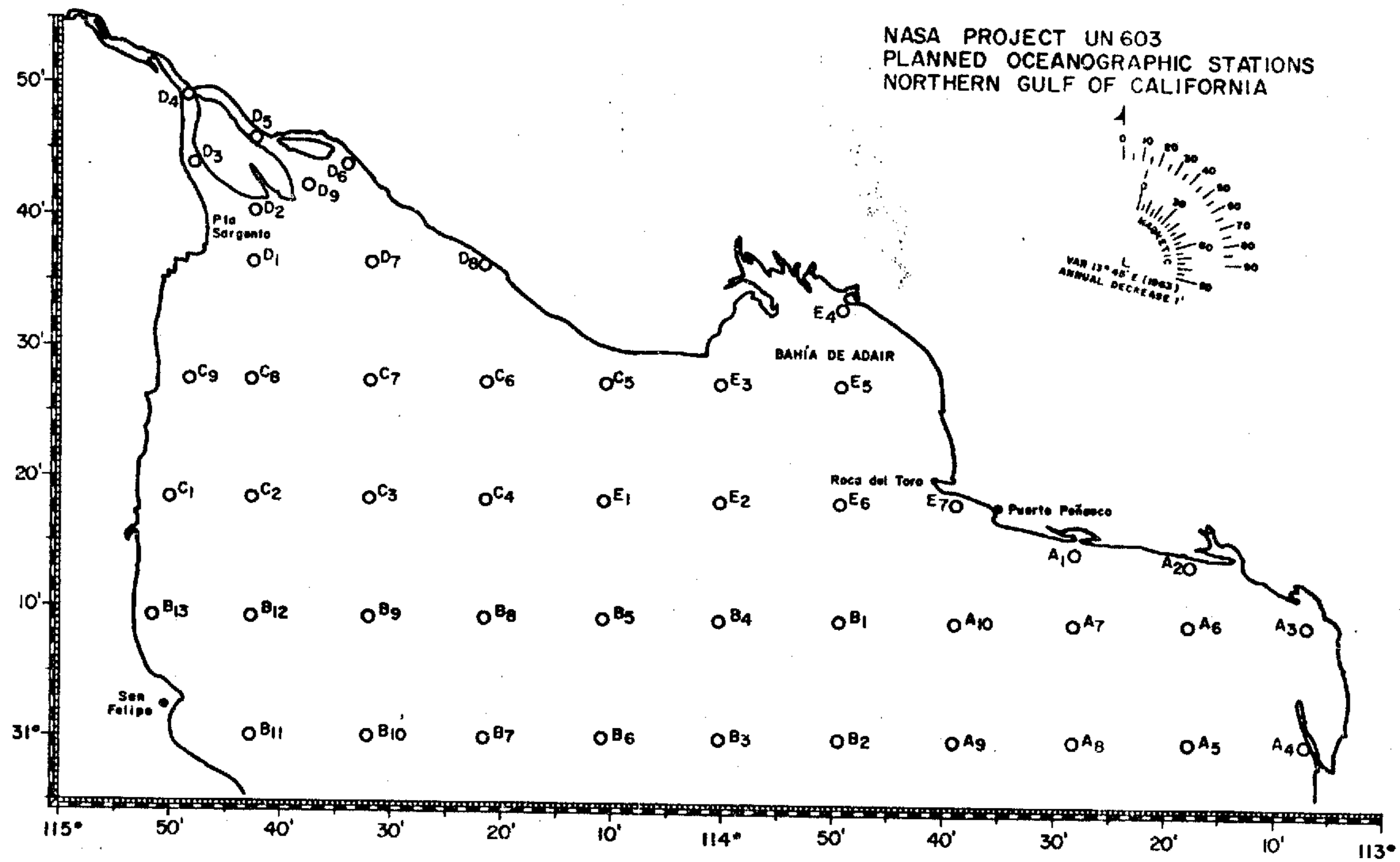


Figure 9. Oceanographic Stations, Northern Gulf of California (For computing purposes, station labels were converted to pure numbers: A1 becoming 101, B1 becoming 201, C6 = 306, etc.)

Table 4

Coordinates of Oceanographic Stations
NASA Project, Northern Gulf of California

Station Number	Station Code	North Latitude (to nearest 0.5')	West Longitude (to nearest 0.5')
A1	101	31° 14.0'	113° 28.0'
A2	102	31° 13.5'	113° 17.5'
A3	103	31° 09.5'	113° 07.0'
A4	104	31° 00.0'	113° 07.0'
A5	105	31° 00.0'	113° 17.5'
A6	106	31° 09.5'	113° 17.5'
A7	107	31° 09.5'	113° 28.0'
A8	108	31° 00.0'	113° 28.0'
A9	109	31° 00.0'	113° 38.5'
A10	110	31° 09.5'	113° 38.5'
B1	201	31° 09.5'	113° 49.0'
B2	202	31° 00.0'	113° 49.0'
B3	203	31° 00.0'	114° 00.0'
B4	204	31° 09.5'	114° 00.0'
B5	205	31° 09.5'	114° 10.5'
B6	206	31° 00.0'	114° 10.5'
B7	207	31° 00.0'	114° 21.5'
B8	208	31° 09.5'	114° 21.5'
B9	209	31° 09.5'	114° 31.5'
B10	210	31° 00.0'	114° 31.5'
B11	211	31° 00.0'	114° 42.5'
B12	212	31° 09.5'	114° 42.5'
B13	213	31° 09.5'	114° 51.5'
C1	301	31° 18.5'	114° 50.0'
C2	302	31° 18.5'	114° 42.5'
C3	303	31° 18.5'	114° 31.5'
C4	304	31° 18.5'	114° 21.5'
C5	305	31° 27.5'	114° 10.5'
C6	306	31° 27.5'	114° 21.5'
C7	307	31° 27.5'	114° 31.5'
C8	308	31° 27.5'	114° 42.5'
C9	309	31° 27.5'	114° 48.0'
D1	401	31° 36.5'	114° 42.5'
D2	402	31° 40.0'	114° 42.5'
D3	403	31° 44.0'	114° 48.0'
D4	404	31° 49.0'	114° 48.5'
D5	405	31° 46.0'	114° 42.5'
D6	406	31° 44.0'	114° 34.0'
D7	407	31° 36.5'	114° 31.5'
D8	408	31° 36.5'	114° 21.5'
D9	409	31° 42.0'	114° 37.5'
E1	501	31° 18.5'	114° 10.5'
E2	502	31° 18.5'	114° 00.0'
E3	503	31° 27.5'	114° 00.0'
E4	504	31° 33.0'	113° 49.0'
E5	505	31° 27.5'	113° 49.0'
E6	506	31° 18.5'	113° 49.0'
E7	507	31° 18.5'	113° 38.5'

Table 5

Cruises, Oceanographic Stations, and Satellite Imagery Orbits,

NASA Project UN603, Northern Gulf of California

CRUISE #[1]	CRUISE DATES INCLUSIVE	STATIONS DONE	ORBIT DATE
			Aug. 6-7; 24-25
101	Aug. 27-29, 1972	27	
			Sept. 11-12; 29-30
102	Oct. 11-15, 1972	44	
			Oct. 17-18
201	Oct. 25-27, 1972	18	
			Nov. 4-5
103	Nov. 15-20, 1972	25	
			Nov. 22-23
104 & 202 (joint)	Dec. 9-18, 1972	36	Dec. 10-11
			Dec. 28-29
105 & 203 (joint)	Jan. 14-21, 1973	43	Jan. 15-16
204	Feb. 1-2, 1973	17	Feb. 2-3
106	Feb. 18-25, 1973	46	Feb. 20-21
205	Mar. 9-13, 1973	21	Mar. 10-11
107	Mar. 26-30	3	Mar. 28-29
108 & 206 (joint)	April 14-16, 1973	18	April 15-16
109	May 1-6, 1973	41	May 3-4
207	May 21-24, 1973	18	May 21-22
110	June 6-13, 1973	27	June 8-9

1. Cruises planned principally by University of Arizona personnel are given a series designation of 100; cruises planned principally by Universidad de Baja California personnel are given a series designation of 200.

4. Mexican Cooperative Activities

Although it was not possible to obtain official permission for plane overflights, extensive cooperation was received from all other official quarters. With the special assistance of the National Institute of Fisheries, necessary individual permits to collect specimens and conduct investigations in Mexico were received from the Secretariat of Industry and Commerce. In the important matter of clearance for ship movement, we received the full cooperation of port authorities in the northern Gulf; specially-printed sailing forms prepared in consultation with the port authorities, and paralleling standard Mexican procedures for local fishing boats, greatly facilitated our operations. Placement of our remote oceanographic buoy in Mexican territorial waters would have been impossible without the deeply appreciated cooperation of the Department of Oceanography of the Mexican Navy. An official description of the buoy and its planned deployment was transmitted to this agency, who published the description in their regular "Notices to Mariners". No difficulties were encountered in this aspect of our program.

The National Council of Science and Technology of Mexico gave much organizational assistance during the early portion of our contract work and was one of the official deposit points for data generated in the program, serving the country in general in this respect. The Council funded a full-support scholarship for one graduate student presently working for the Master's degree on the Tucson campus, using our ERTS-1 imagery for his thesis work.

The above scholar is Lieutenant Gustavo Calderón of the Mexican Navy, released by their Department of Oceanography for the purpose of studying in our program under the above scholarship.

The National Agency for External Space of Mexico lent valuable support and approval to our program, and was another standard data recipient.

The National University of Mexico undertook shipboard participation in our program (which made them automatically a data recipient). Their studies included determinations of primary productivity, distribution of heavy metals in northern Gulf organisms, and seasonal distribution of commercial shrimp larvae in the area.

The University of Sonora has limited staff in fields related to this project and were not able to participate in the shipboard scientific work. They were, however, a most important participant by virtue of allowing use of the research vessel "ADVENTYR" for the project and undertaking all manner of other activities to facilitate the work. They are a standard data recipient and are presently considering the possibility of special studies of the nearshore land areas included in the ERTS-1 imagery for land development, hydrological, and geographical studies.

The University of Baja California, through its well-developed Institute of Oceanography, was our most active, direct partner in field research. Their staff of qualified oceanographers and biologists, supplemented by a rota of chosen, higher division students, played a strong part in the cruise activities and contributed important skills and equipment to the project. UABC modified an earlier program of studies in the northern part of the area to convert to our standard oceanographic station program, and one station (D-9) was added to our original grid to complete the accommodations. Throughout the period of the contract work scientists at the University of Arizona and the University of Baja California have maintained close working contact by mail and by telephone--sometimes on an almost daily basis. This mutually beneficial cooperation will undoubtedly continue in a number of special projects, long after the ending date of the present contract. New and different cooperative ventures for the future are under discussion between scientific colleagues brought into working contact through the present program.

In every respect and without any exception, this program of "hands across the border" has been a resounding success and a happy experience at all local levels where working contact was established, whether with government agencies, local authorities, or members of the fishing community.

5. Major Difficulties Encountered

Refusal of permission for overflights of Mexican territorial waters made imagery analysis more difficult and compelled a number of conclusions to be presented in more tentative form than would otherwise have been the case. Earlier plans for studies on productivity and commercial fishing intensity also had to be dropped. During the initial period of the contract before refusal of overflight permission was forthcoming as a policy decision, cruise planning for required coincident ground observations was frustrating. Inevitably, when ship work was planned to coincide with a flight which did not materialize because of a last minute denial of permission, it was too late (or too early) to replan for coincident ERTS-1 overpass coverage. By the time all plans for airplane overflights were discarded (when the policy decision refusing permission was received), we had already missed many ERTS-1 overpasses. Thus, the necessary ground truth was not available to the imagery interpretation team until December coverage was obtained.

The most important single area of difficulty was encountered in the area of timing to fit contract requirements. The absence of firm advance notice of contract approval reduced get-ready time to almost zero, and prevented the systematic approach to preparations which had been anticipated at the time of submission of the original proposal. Arrangements for procurement, overhaul, and modification of the research vessel therefore extended well into the time when the ship should have been at sea collecting data for seasonal coverage. Delivery delays on equipment drastically set back the timing on buoy construction and deployment, particularly in the area of electronics. As a result, while one buoy was deployed and successfully tested during the contract period, the test was brief and plans for the second buoy had to be dropped. It had been hoped that the buoy project could result not only in the development and testing phases covered by the contract, but might also provide valuable telemetered data for general oceanographic analysis.

Discrepancies between listed specifications and actual design of the DCP and the Field Test Set produced problems for the electronic engineers, as did the non-availability of central repair facilities for this equipment (see section II-2).

Foul weather and mechanical difficulties interfered with cruise work schedules, but such common problems of work at sea were well in mind during the planning stage and are not here represented as being excessively beyond expectations. (There were, it must be admitted, surprises . . . Imagine, if possible, the tragi-comic situation of a ship's rudder falling completely off during active maneuvering at sea on station work!)

6. Meteorological Conditions

The meteorological conditions of the northern Gulf of California and surrounding area have previously been described by Green (1969), Roden (1964) and others. While these accounts generally present an adequate description of the meteorological conditions which obtain in the area, the data on which their conclusions are based are from meteorological stations removed from the site of this study and located inland (San Luis, Rio Colorado, Yuma, El Mayor, etc.), with the exception of data quoted by Green from San Felipe and Puerto Peñasco. General references on regional and national climates, such as Ward and Brooks (1936) and Page (1930), have also been employed.

Climatic descriptions of the area have included estimates of monthly means of dry bulb and wet bulb air temperatures, relative humidity, precipitation, and wind speed. While these data are useful, also of interest and particularly to biologists, are estimates of extreme values and total ranges within each month. In this regard, Roden (1964) reports that "winter frosts may occasionally occur near the coast in the northern region," and Thompson (1968) states that temperatures as high as 50° C have been reported from the Colorado River delta area. Both authors quote a mean annual range of 18° C; Green (1969) makes no mention of these aspects of the regime.

Green does examine the climatic variations within the area of the northern Gulf of California and has shown that the western shore of the Gulf of California at San Felipe is slightly hotter and dryer than the Sonoran coast at Puerto Peñasco. No comparison of mean monthly air temperatures between these two shore stations and northern Gulf oceanographic stations has appeared, probably due to the sparse data available at the time of Green's study.

Two sets of data are presented below for comparison with that of Green. In Table 6, data collected by technicians at the Puerto Peñasco Marine Laboratory for the period 1971-1973 (thru June) are displayed as mean monthly estimates. The temperature data are from daily observations of a maximum-minimum thermometer. See section III-1 for a description of the Puerto Peñasco Laboratory facilities and the instrumentation referred to here. In Table 7 are displayed data which were collected aboard the R/V "ADVENTYR" during oceanographic cruises in the northern Gulf of California during the period August, 1972 - June 1973. Reference should be made to section III-2 for a discussion of the procedures, instrumentation, sampling schedule and locations of oceanographic stations.

a. Temperature

The data in Table 6 differ from that presented by Green (1969). Calculations based on Green's data indicate a mean annual range (difference between highest and lowest monthly means) of 18.3° C and 20.5° C were observed in 1971 and 1972 respectively. The observed 1971-73 seasonal cycles also differ in the

Table 6

Monthly Mean Climatic Data for Puerto Penasco, 1971-1973

	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Dry Bulb °C.	1971	11.62	13.88	16.08	18.21	22.13	26.61	30.85	31.83	30.65	22.43	17.13	12.59
Minimum	1971	-8.3	1.7	-1.1	2.2	9.4	15.6	18.3	21.7	16.7	1.2	2.2	0.6
Maximum	1971	30.6	30.6	31.1	35.6	32.8	37.2	40.6	40.0	42.8	38.9	29.4	25.8
Range	1971	40	29	32	33	23	21	22	18	26	37	27	25
Mean Dry Bulb °C.	1972	12.01	14.96	19.06	20.70	23.67	28.07	32.50	31.51	29.48	23.92	16.53	13.22
Minimum	1972	-1.7	2.2	3.3	5.0	11.7	17.8	22.2	21.1	16.7	9.4	3.3	-3.9
Maximum	1972	25.6	28.3	32.2	33.9	35.0	37.8	41.7	39.4	40.6	36.7	31.1	27.8
Range	1972	27	26	29	28	23	20	20	18	24	27	28	32
Mean Dry Bulb °C.	1973	12.37	15.52	15.97	18.73	23.34	28.31						
Minimum	1973	-0.6	3.9	5.0	5.6	10.0	15.5						
Maximum	1973	25.6	27.8	26.7	32.7	34.4	43.3						
Range	1973	26	24	22	27	24	28						
Dominant Wind Direction	1971	N & E	no dom.	East	South	South	South	South	SW	South	North	NE	NE
	1972	NE	no dom.	NE	SW	SE	South	SE	South	SW,S,SE	no dom.	North	North
	1973	North	no dom.	South	South	South	SE						
No. of Days With Rainfall	1971	0	0	0	0	0	0	0	2	0	0	0	0
	1972	0	0	0	0	0	0	0	0	0	4	0	0
	1973	0	1	0	0	0	0						
% of Days Clear	1971	69%	77%	85%	70%	84%	85%	35%	27%	64%	62%	48%	39%
	1972	81%	59%	87%	63%	77%	87%	48%	39%	53%	26%	66%	55%
	1973	55%	46%	52%	93%	100%	75%						

Source: Hendrickson, 1973

Table 7

Monthly Mean Climatic Data Observed at Oceanographic Stations Aug. 1972 - June 1973

	1972				1973				
	Aug.	Oct.	Nov.	Dec.	Jan.	Feb.	April	May	June
Mean Dry Bulb °C.	29.48	27.37	19.97	13.54	16.24	16.78	19.08	22.04	26.95
Minimum	25.5	22.0	15.2	6.7	5.0	8.9	14.7	19.5	26.0
Maximum	31.0	32.0	25.5	17.4	19.7	21.8	21.7	26.2	29.0
Range	6	10	10	11	15	13	7	7	3
Mean Wet Bulb °C.	---	---	---	8.67	13.03	12.76	14.32	18.4	24.18
Minimum	---	---	---	3.9	7.2	6.7	11.0	14.4	21.5
Maximum	---	---	---	17.5	16.7	17.8	18.5	21.5	26.0
Range	---	---	---	14	9	11	7	7	4
Mean Rel. Humid. %	---	---	---	57.8	69.0	61.0	56.0	65.0	78.0
Mean Wind Speed	4.6	4.1	5.6	9.0	7.5	10.3	12.3	8.17	9.6
Dominant Wind Direction	South	North	North	North	East	North	South	South	South

warming phase from the average seasonal cycle presented by Green, in that the period of most rapid heating occurred during the February-March period and not March-April as she estimates. Seasonal curves plotted from the observed 1971-1973 data are contrasted with those estimated by Green in Figure 10.

A comparison of the two sets of data indicate that means of all months observed are from 0.2 to 2.4° C higher in our data than the estimates presented by Green, with the greatest differences occurring in the spring and summer months. Green does not state the method of temperature measurement, the source of the data network, or the assumptions made in her preparation of "hourly meteorological data"; the inference is that her tables were prepared from thermograph data or information of a similar nature. The mean dry bulb temperature data presented here are averaged maximum-minimum temperature measurements, and thus are not strictly comparable to measurements made at regular intervals throughout discrete time periods. The chief difference would lie in the variance of the two distributions and the relative emphasis on the variation of diurnal extremes within the month vs. variation of the mean daily temperature within the month. If Green's source data network represents measurements made at regular intervals throughout the day, this could account for the differences noted above. Means derived from averaged daily minima and maxima might be expected to be higher than means derived from periodic data (Miller, 1957, pg. 9). In any case, the two data sets are surely representative of the seasonal cycle which occurs at Puerto Peñasco and do not imply significant environmental change through the years in question.

Also of interest in Table 6 are the estimates of maximum temperature range observed within each month. Frost and sub-zero temperatures occurred in January of each year observed and sub-zero temperatures were also recorded in December, 1972 and March, 1971. It would appear that winter freezing is more common than Roden (1964) estimated. The variation in air temperature within a month can be phenomenal. Minimum and maximum temperatures recorded within each month and the calculated maximum ranges are listed in Table 6. The greatest range within any single month was observed in January, 1971, where the temperature varied 40° C within a 31 day period. Normal expected temperature range for the winter months appears to be 28° C, and for the summer months it decreases to 21° C. Not listed in Table 6 are the diurnal variations in temperature. These tend to follow the cycle of the monthly range. Diurnal variations in temperature are maximal in the winter months, with an average of 19° C in January and are minimal in the summer months, with an average of 10° C in August.

Local climatic conditions do vary within the northern Gulf area. In Table 7 the mean monthly air temperatures recorded at oceanographic stations in the northern Gulf of California indicate that the sea acts as a source of heat in the winter and as a heat sink in the summer. This effectively moderates the extremes and generally dampens the seasonal cycle, as shown in Figure 11. While the mean temperatures do not vary significantly, the absence of the extremes noted at Puerto Peñasco could have a definite effect on the biota of the two northern Gulf islands, Isla San Jorge and Roca Consag. The monthly winter air temperature range at oceanographic stations varied from 11 to 15° C as compared

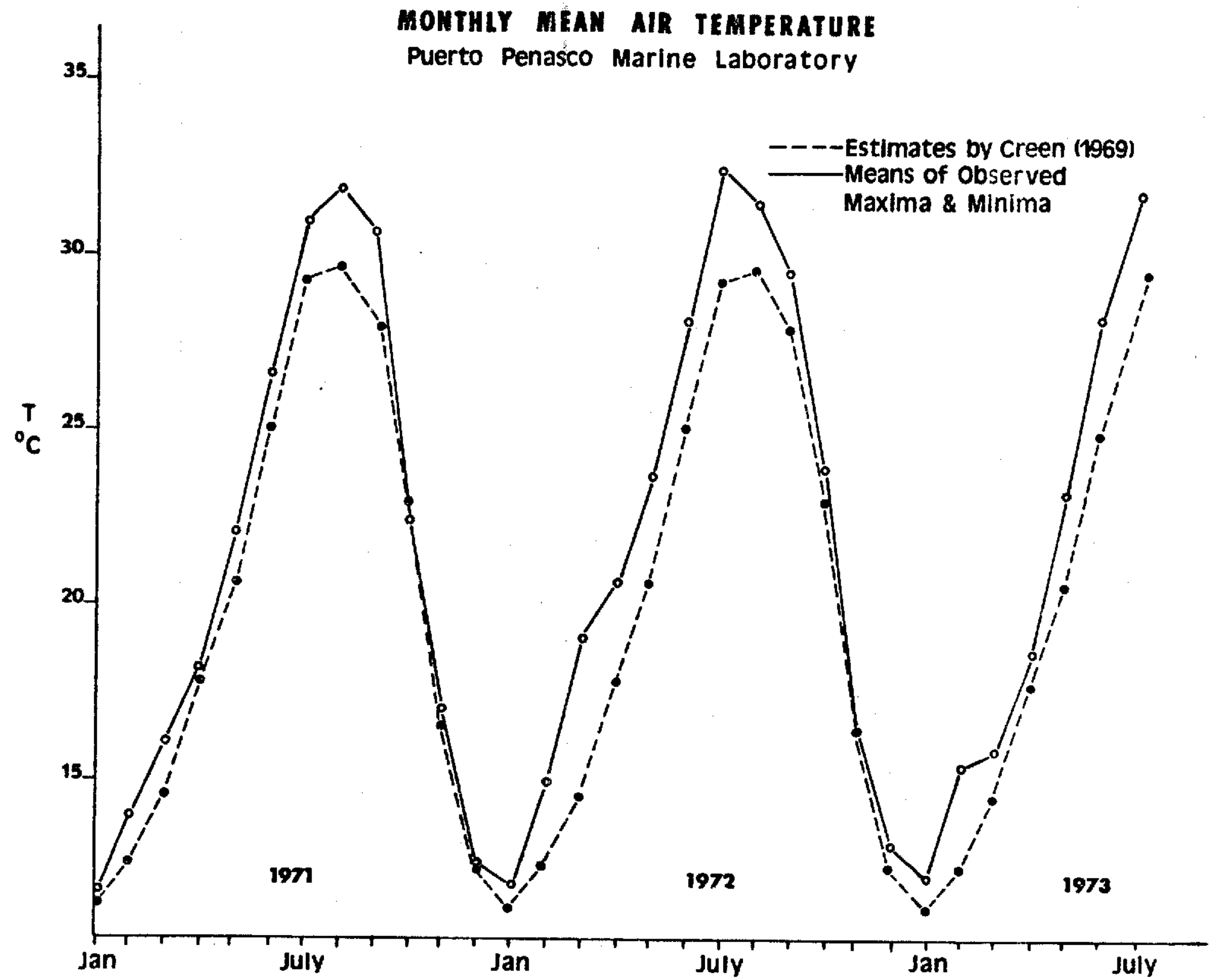


Figure 10. Monthly Mean Air Temperature, Puerto Penasco Marine Laboratory

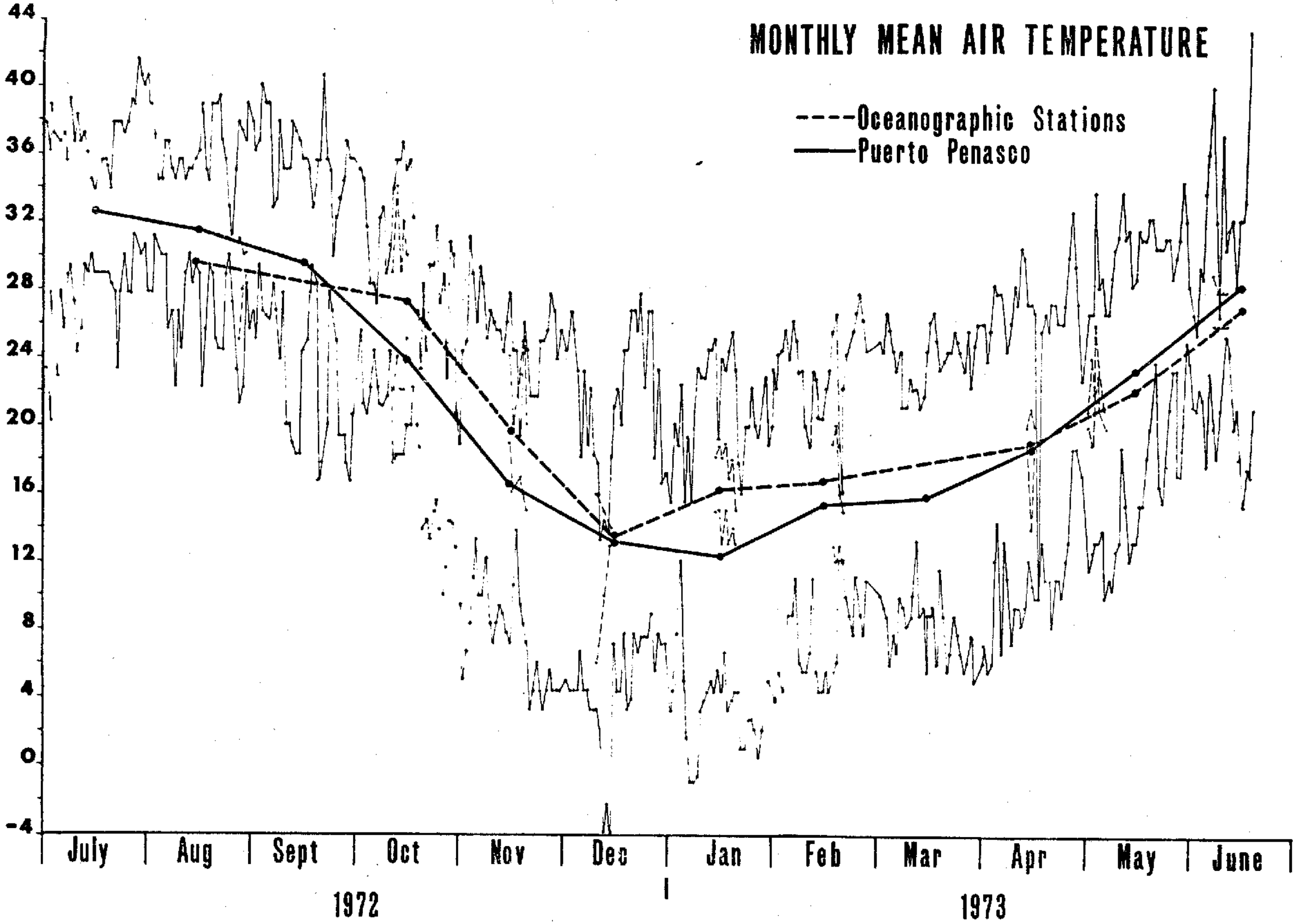


Figure 11. Monthly Mean Air Temperatures, Oceanographic Stations Compared with Puerto Penasco Marine Laboratory.

with 28° (estimated normal range) or 40° (observed abnormal range) at Puerto Peñasco. Since the oceanographic stations in this enclosed area include many near-shore stations (8 nautical miles or less), the temperature range at Roca Consag could be significantly less than at shore stations, since the island is located in the middle of the northern Gulf and is under the influence of the deep waters of the central Gulf. The monthly range observed for the summer months at sea was 3-6° C as opposed to 10° at Puerto Peñasco. Diurnal variations were similarly reduced.

Due to the nature of the sampling, no conclusions can be drawn concerning minor differences in monthly means between shore localities, e.g. between Puerto Peñasco and San Felipe or El Golfo de Santa Clara.

Wet bulb temperatures are recorded in Table 7 . These data are insufficient for analysis and are not comparable with those of Green, since they were recorded from oceanographic stations.

b. Precipitation

The number of days in each month for which rainfall was recorded appears in Table 6. Amount of rainfall is not recorded. From Table 6 , it can be seen that only on 7 days of the 2 1/2 years was rainfall recorded in the Puerto Peñasco 1971-1973 observations. This seems inordinately low, and is probably related to the fact that weather conditions are recorded only once each day and developments before or after that hour may not have been noted. In addition, rainfall in the area is highly localized. Rainfall occurred on two successive days in February, 1973 as recorded during an oceanographic cruise, but only one day of rain was noted in Puerto Peñasco. The rains which occurred in October, 1972 were significant in that they contributed to runoff in the northern Gulf, which measureably decreased the local salinity for a short period of time (Alvarez, 1973).

The percentage of days within each month for which cloudless sky conditions (clear) are noted appears in Table 6 . Though a high variability is present, the data indicate that this area enjoys relatively clear weather throughout most months of the year. Again, since sky conditions are recorded in the morning, no indication of afternoon cloudiness is given. As observed on the cruises, mornings were usually clear with evidence of cloud development or cloud movement into the area usually apparent by noon. In the afternoon, clouds were fully developed and by mid-evening had begun to disperse; nights were commonly clear.

c. Wind

Wind speed data for the 1971-1973 period at Puerto Peñasco have not been incorporated into this report because of doubts as to the accuracy of the recording anemometer at the marine station, and Green's (1969) data remain the

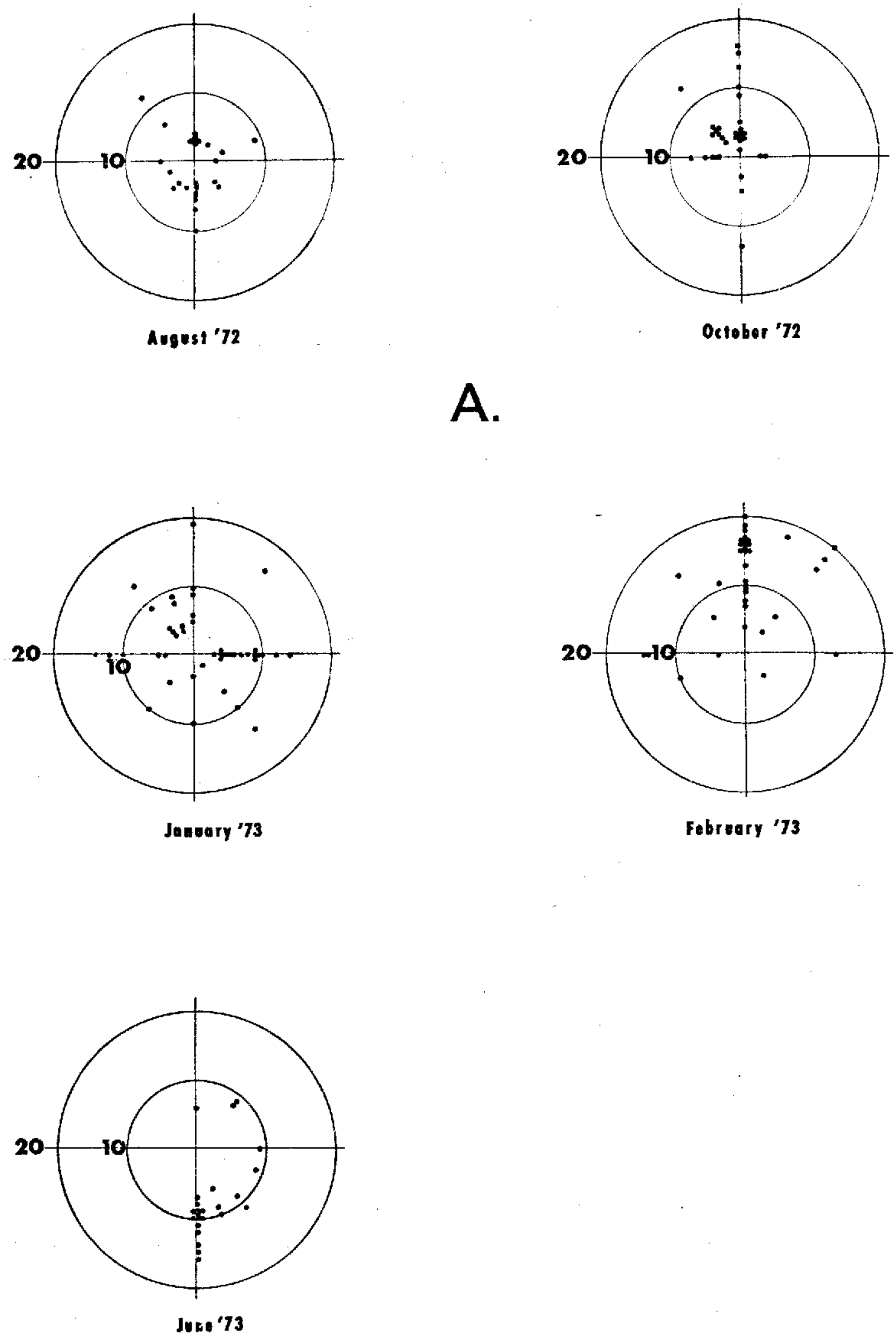
primary reference material for this parameter. In general, the trend of the 1971-1973 land observations followed Green's data (i.e., higher wind speed during the summer months, May-October, than in the winter). Winds recorded during the oceanographic cruises, as displayed in Table 7 , seem to show an opposite tendency, i.e., for winter winds to be greater. On second consideration, however, the low values recorded for August and October can be attributed to unusually good weather enjoyed during both of those cruises; the high value for April is also reflected in an extreme April record from Puerto Peñasco indicating unusual circumstances were obtaining throughout the area. Other discrepancies can be accounted for by the numerous ship sampling locations and a high diurnal variability. Winds observed during the oceanographic cruises are presented in Figure 12 A and B.

Wind direction observations for the period 1971-1973 are in the form of two daily observations (see section III-1). These have been analysed to yield a frequency distribution of directions observed within each month. The direction most frequently observed within each month appears as the "Dominant Wind Direction" entry in Table 6.

It is apparent that the wind patterns have been remarkably stable at Puerto Peñasco throughout the period 1971-1973. Winds blow from the southeast, south or southwest during the months April - September and from the north, northeast, and east (less frequently) during November, December and January. February, March and October are months of transition between these patterns and are characterized by variable wind direction.

These same patterns are present in the wind direction data gathered aboard ship during the period. The ship data represent observations gathered at higher frequency within a day, and over a very short period within the month, i.e., average of 8-10 observations/day for 8 consecutive days within the month. In addition, the observation locations aboard ship varied by as much as 90 nautical miles within a single day. It is therefore, somewhat surprising that the data agree so well. Though not conclusive, these data may indicate that the Puerto Peñasco observations can be used as a synoptic measure of wind conditions in the general area comprising the northern Gulf of California.

The seasonal variation in wind described above serves to accentuate the seasonal climatic cycle observed at Puerto Penasco. Northerly winds during the winter months bring cold, dry air from the northern deserts and would move the warmer air residing over the water mass toward the south, thus accentuating the effect of the arid land mass on the local climate. Conversely, the summer southerly winds move the moist, warm tropical air up from the south and enhance the tropical oceanic climate characteristics of the region. The summer winds also help to moderate the extreme heat which often develops over the inland deserts near Puerto Peñasco. This may explain why the 50° C temperatures reported by Thompson and others to occur in the Colorado River delta area do not occur at Puerto Peñasco, less than 30 miles to the south and 60 miles east.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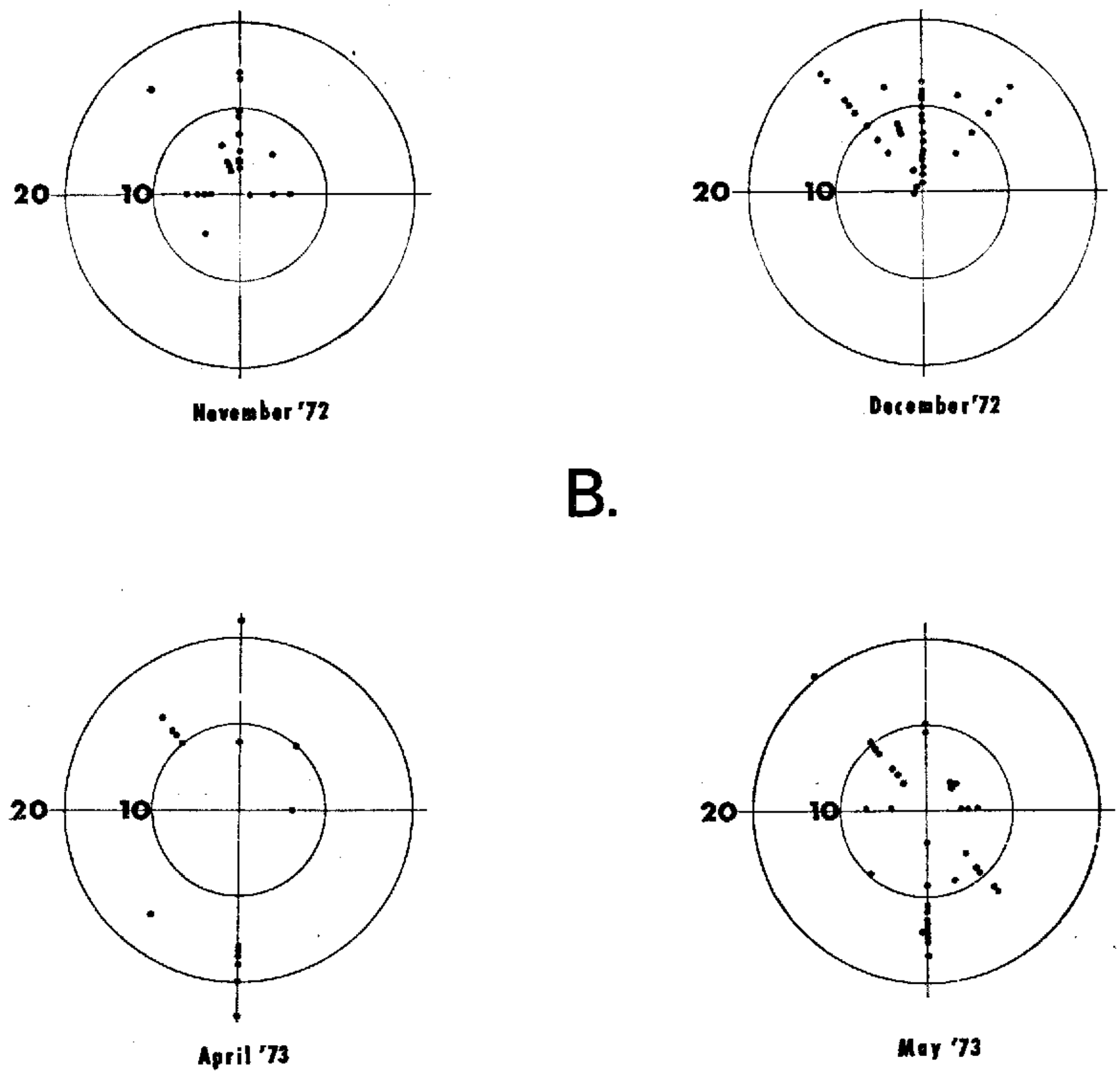

Figures 12 A and 12 B. Wind Observations at Oceanographic Stations. Concentric circles represent wind speeds of 10 and 20 knots. Each dot represents 1 observation.

Puerto Peñasco wind observations also appear to have a high degree of non-random variability in the directional coupling of morning and afternoon winds. Though analysis of these data are still underway, the preliminary indication is that afternoon wind direction is a probabilistic function of morning wind direction within the seasonal cycle described above.

Wind direction and speed are also related, as first reported for Puerto Peñasco by Green (1969). In general agreement with Green's figure (1969, p. 12), winds from the northwest, north and northeast were strong but highly variable. These winds commonly reached speeds up to 20 knots and blew over a period of days. Winds from the east were generally light and only rarely developed speeds greater than 10 knots. Winds from the south were commonly greater than 10 knots and at times developed into storm gales. Westerly winds were usually light, though at least one storm was dominated by westerly gales. In general, the most violent storms are from the south and these generally occur in the late summer and fall. Blowing from the north or northwest, winter storms are less violent; they create smaller seas, but are of longer duration.

7. Analysis of Oceanographic Data

Oceanographic data were collected in the northern Gulf of California during the period August, 1972 - June, 1973 in a series of 9 cruises. The modified research vessel "ADVENTYR" used during this period has been described in section III-2. The oceanographic stations planned for monthly visitation are described in section III-3. The instrumentation and procedures employed in obtaining the data have also been described in section III-2.

The timing and route of the monthly cruises were governed by a number of criteria. Although the original plan called for monthly sampling on a regular schedule, the following elements were also considered:

1. Scheduling of overflights of the test area requiring ship-gathered coincident ground observations.
2. ERTS-1 overpass schedule requiring ship-gathered coincident ground observations.
3. Condition of the research vessel (i.e., planned maintenance or necessary repairs).
4. Tidal series within the cruise period for safe entry into the delta area and Colorado River channel.
5. Weather conditions.
6. Locations of safe anchorages within the northern Gulf for small vessels.

The timing of the cruises with respect to satellite coverage, etc. has already been discussed (see Table 5). The cruise routes for the 9 principal (U. of A.) cruises are shown in Figures 13, A-I; an average of 34 stations were worked on each cruise, requiring an average of 7 days, including return to the home port at Puerto Peñasco.

All data were processed according to NODC guidelines and were run through a series of computer programs written by our staff to meet specialized requirements of the project. Because this was an investigation requiring a high degree of international cooperation and confidence, a data library was organized to process and disseminate data to all cooperating scientists and institutions.

Figure 14 illustrates the standard analysis routine for data collected on Gulf cruises. All processing was carried out at the University of Arizona Computer Center using the CDC 6400 computer and Calcomp Plotter.

As is indicated in Figure 14, a search of the literature was conducted and all published (and some unpublished) physical oceanographic data known to have been collected in the northern Gulf of California, north of 29°40' North latitude were selected, coded and keypunched, and added to the data library for later comparison with our own observations. These data will be discussed in section III-8.

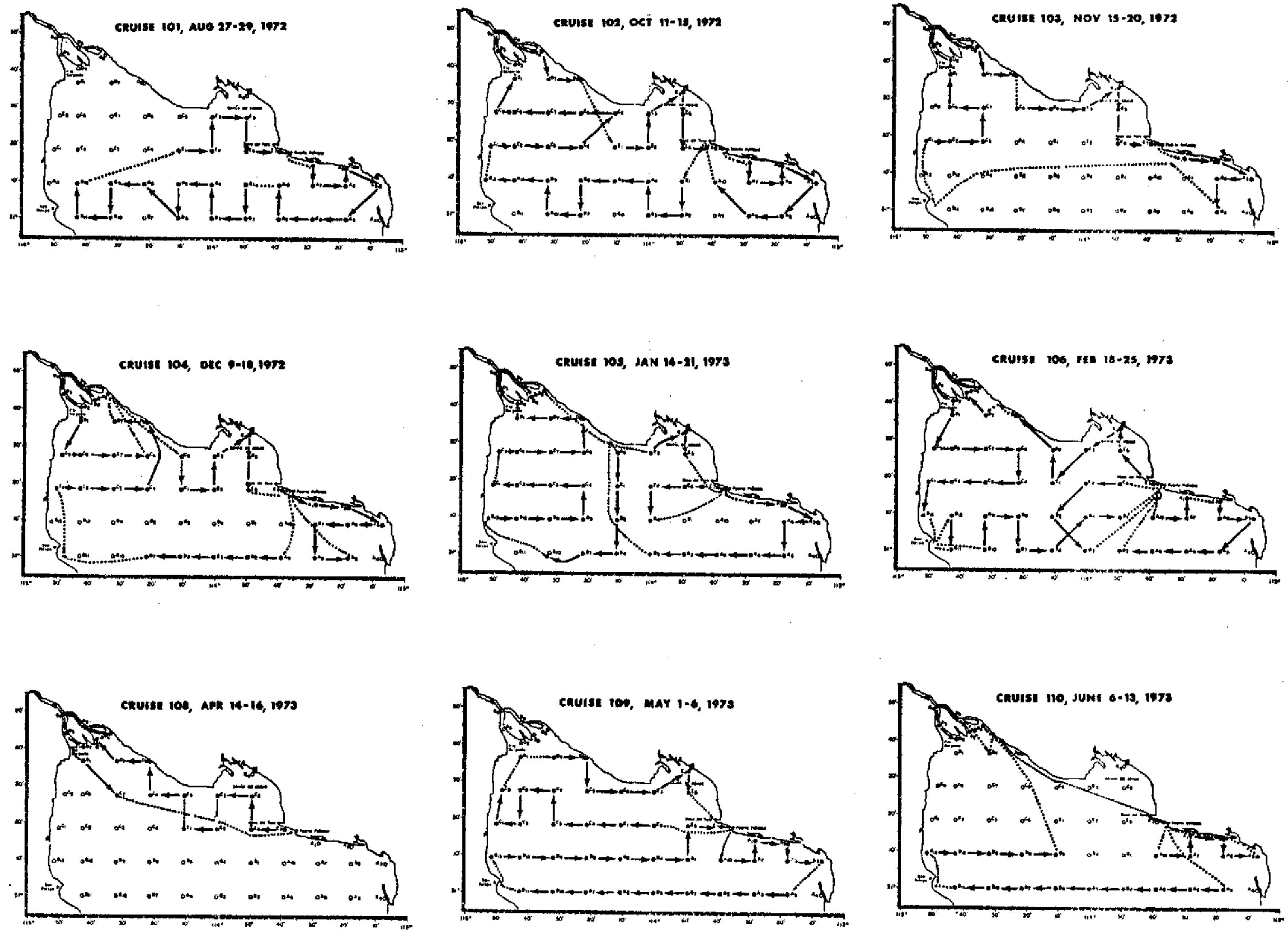

Figure 13. Routes Followed by R/V "ADVENTYR" on Oceanographic Cruises.

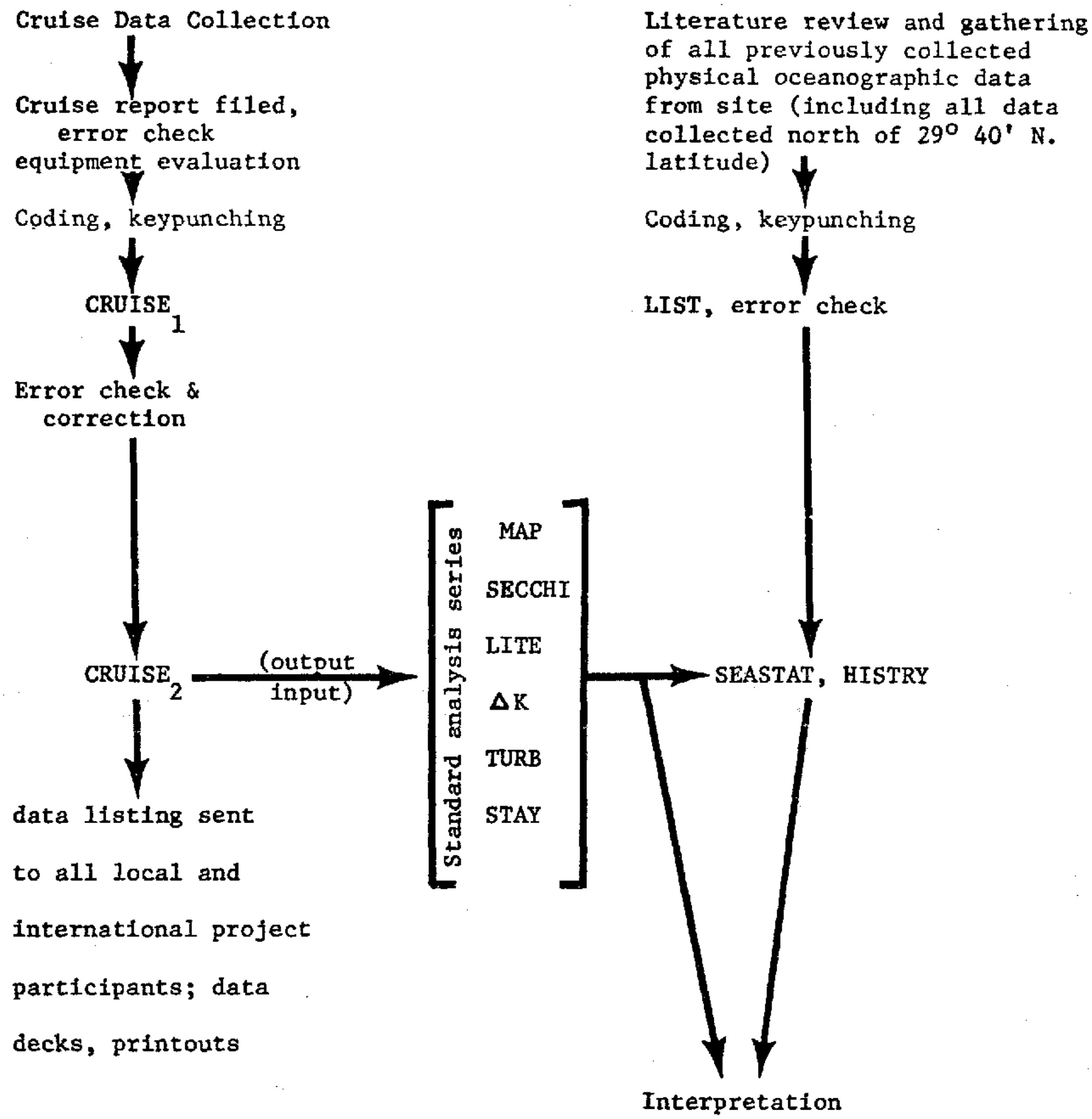

Figure 14. Standard Analysis Routine for Oceanographic Data
(Terms in block capitals are names of special computer programs formulated for this project; subscript numbers on program "CRUISE" indicate preliminary and final analysis stages.)

With experience gained during the early cruises an impression was formed of the nonhomogeneity of the area, and the presence of localized distributional patterns was hypothesized. The distribution of salinity, temperature and turbidity within these areas appeared to be governed by factors which were identifiable and area-specific. These impressions have persisted and the result is reflected in the analyses of the data. Based primarily on this hypothesis, the northern Gulf was partitioned into 3 areas, each associated with a specified set of oceanographic stations. The subsets have been identified by characteristic names: "Shore Stations" describes all stations in the area around the perimeter of the northern Gulf which lie within 10 nautical miles of any low-tide shoreline or island (Roca Consag excepted). "Sea Stations" describes the southern and central oceanographic stations comprising the deepest part of the study area. "Delta Stations" are those which are under the influence of the Colorado River channel or sedimentation plain; these latter stations also conform with the pattern sampled regularly by the Universidad de Baja California. The subsets are displayed graphically in Figure 15; it is clear that some oceanographic stations fall in more than one of the three groups and the greatest degree of overlap is found in the north.

For each month, means were calculated for the whole northern Gulf (all stations taken together) and for each of the three subgroups. The results are discussed below.

a. Temperature

Sea surface or near-surface temperature is highly variable in the northern Gulf of California. In general, surface temperatures follow closely the trends in ambient air temperature, both seasonally and diurnally, as would be expected for a shallow, partially enclosed evaporation basin that is flushed by strong tidal currents. The shallowness of the area under study is illustrated by the fact that only at 50% of the 47 regular stations were measurements greater than (or equal to) 20 meters possible.

Mean sea surface temperatures calculated from observations made during the 9 U. of A. cruises of the R/V "ADVENTYR" are displayed in Table 8. The means have been calculated for the entire test area and for Sea and Delta station subgroups. The means for Shore stations are not displayed but can be inferred from the other data; Shore stations tended to react to seasonal change in much the same manner as Delta stations, but were not as well mixed by the tidal currents. Thus, their temperatures were slightly cooler in the summer and slightly warmer in winter ... well within the range exhibited by the Delta stations.

As is evident in Table 8, the mean annual range for all northern Gulf stations is 15°C; for the Sea and Delta stations the observed mean annual ranges were 12° and 16° respectively. It is of note that Rosenberg's (1969) estimate of 16°C is based on Puerto Peñasco data, a Shore station under the terms of this discussion. Mean minimum and mean maximum temperatures are also displayed in Table 8 and serve to illustrate the variation about the mean within

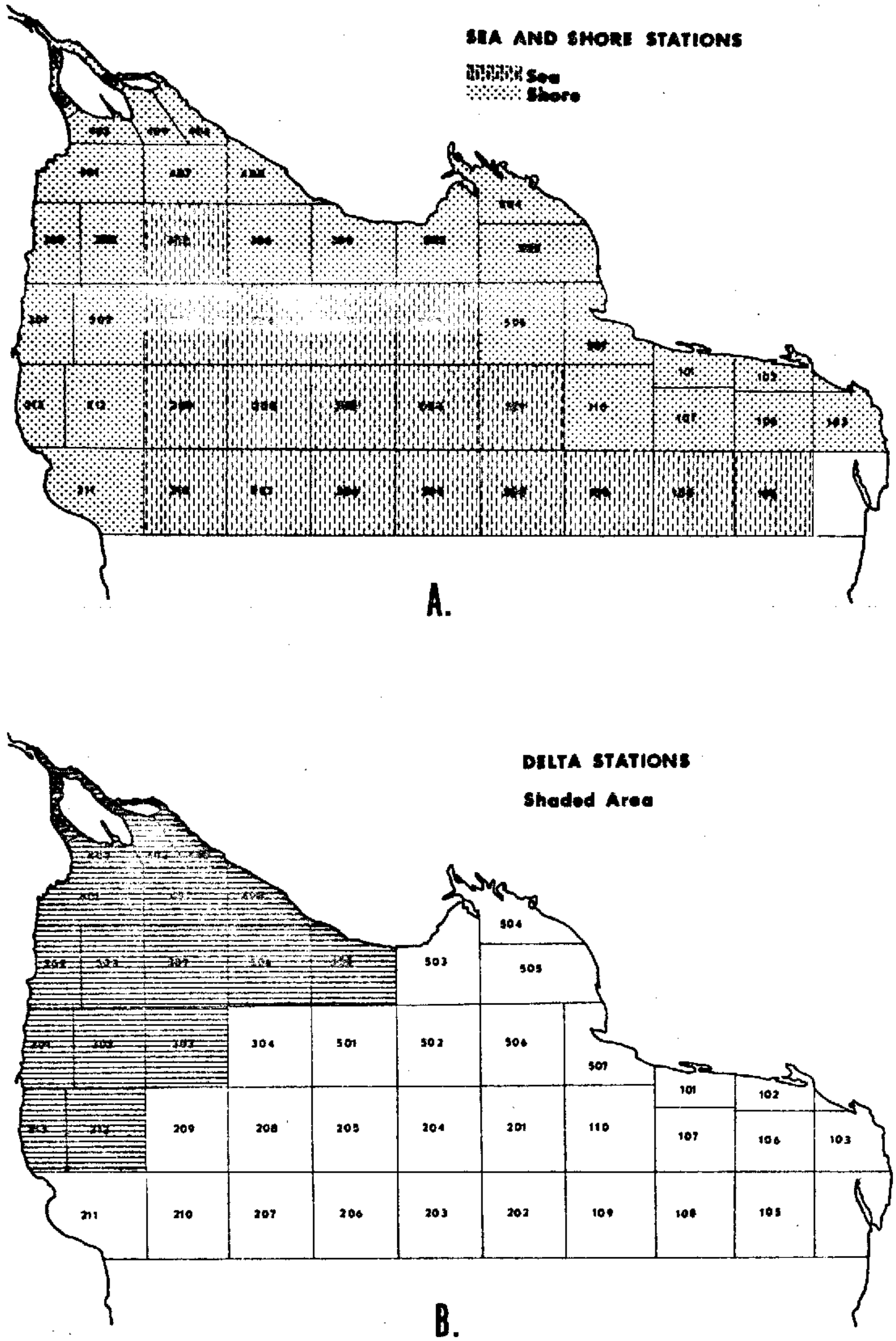

Figure 15. Division of Study Area into Catogories: A.- Sea Stations, Shore Stations; B.- Delta Stations.

Table 8

Mean Surface Temperature,

Gulf of California North of 31° N. Latitude

	1972						1973					
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
All Stations												
Mean Surface Temperature	--	29.3	--	26.2	19.4	13.9	15.3	16.2	--	18.7	20.6	25.0
Mean Minimum	--	28.7	--	24.9	17.1	9.3	12.9	13.1	--	18.0	19.1	23.3
Mean Maximum	--	30.1	--	27.5	21.8	18.5	17.6	17.8	--	19.1	22.3	27.4
"Sea" Stations												
Mean Surface Temperature	--	29.2	--	--	21.6	17.6	16.9	17.0	--	18.4	20.1	23.8
Mean Minimum	--	28.6	--	--	21.2	16.1	15.5	15.6	--	18.3	19.0	23.2
Mean Maximum	--	29.8	--	--	22.2	18.5	17.8	18.4	--	18.5	22.0	25.0
"Delta" Stations												
Mean Surface Temperature	--	--	--	25.9	18.8	12.1	13.9	15.4	--	18.7	21.2	26.7
Mean Minimum	--	--	--	24.8	16.7	9.0	12.5	14.4	--	17.6	19.9	26.1
Mean Maximum	--	--	--	27.2	21.0	16.9	16.2	16.4	--	19.2	22.8	28.3

each of the subgroups. The mean monthly range for Sea stations varies only 2-3^{o} throughout the year while the same statistic calculated for the Delta subgroup varies from 8^{o}C in December to 2^{o} in June.

The Delta region serves as an area of enhanced thermal transfer between the arid desert atmosphere and the more thermally stable waters which replenish the northern Gulf from the central area. Delta stations dynamically reflect the seasonal air temperature cycle of the land and clearly show the early warming trend which begins to develop in February. At the Sea stations, on the other hand, both warming and cooling are slower and more determinate, lacking short-term temperature excursions. At the Sea stations, February is still a true winter month.

The Delta region is subject to influxes of water from tidal channels and broad flats which further reflect diurnal temperature extremes. For example, in December two surface measurements of 8.2^{o}C and 8.8^{o}C were made during low tide in the Colorado River channel -- these differed from the overnight minimal air temperature by approximately 1^{o}C.

Roden (1964) reported that the lowest temperatures (minima of 14^{o}C) are found in the vicinity of Isla Angel de la Guarda and "not in the upper shallow Gulf", but the above extremes and other figures from the present work refute this. Our data indicate that the mean surface minima of the Delta stations are well below this (see Table 9, pg. 51, where even the means of our collected data fall below 14^{o}C at the surface for Delta stations during December and January). For larger water masses, Roden's (1964) conclusions might be true, but it seems clear that this situation is altered in the northern Gulf where successive waves of very cold surface water are generated in the Delta, move southward and gradually warm as they meet the warmer waters arriving from the deep central Gulf. Figure 16 illustrates this for January.

Table 9 presents a summary of mean temperatures in the near-surface layer, to a depth of 25 meters. The mean surface temperature data for November conform with those estimated by LaViolette and Chabot (1969) from NIMBUS II HRIR data for the northern Gulf of California. Their estimates of mean surface temperatures agree with our estimate of 19.4^{o} if the following points are considered: 1) The Nimbus II data is from the period November 11-15, 1966 and our sampling period during 1972 was November 15-21. The shape of our seasonal curve for sea surface temperatures predicts that a 3^{o} increase in the mean would result from a one-week setback in sampling period. This renders the two results essentially equal. 2) The variation between seasons, and the displacement forward or backward of the cooling portion of the seasonal curve could greatly influence any measurements made in November. Thus, even if LaViolette's temperatures may be underestimated by 2^{o}C, the differences between his 1966 data and our 1972 data are not significant.

In the months of August and February the upper 25 m is almost isothermal. This agrees with observations reported by Roden (1964) and Rosenberg (1969). The months which show maximum change in temperature with depth appear to be June and October, though the data are not complete. In Figures 17A and 17B the monthly mean temperatures for surface and 10 meters are plotted for the Delta and Sea stations. The two cycles are contrasted on the same graph, for a depth of 10 meters, in Figure 18. The most important features of these figures are:

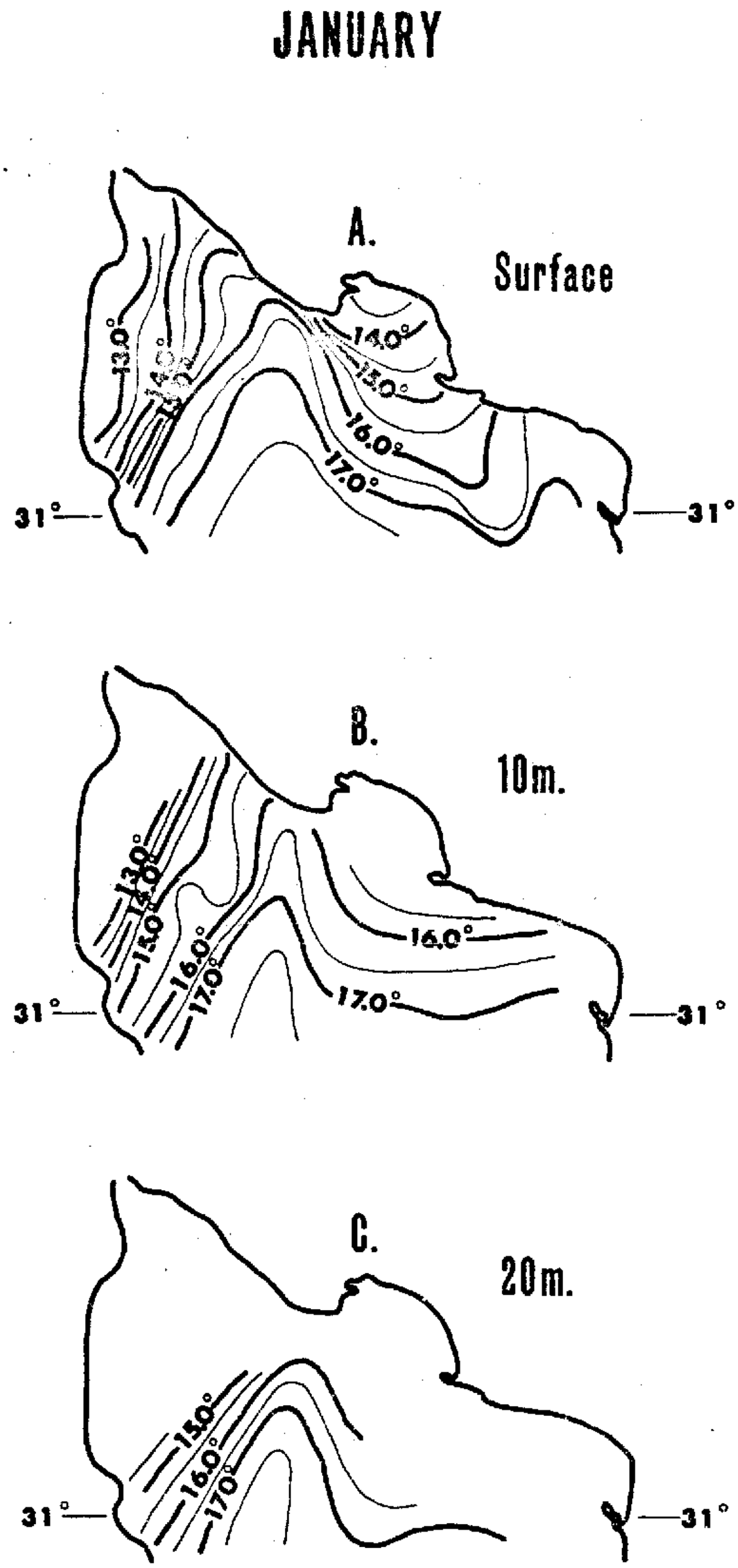

Figure 16. Isotherms for Northern Gulf of California, January, 1973: A.- Surface; B.- 10 Meter Depth; C.- 20 Meter Depth.

Table 9

Mean Temperatures of Near-Surface Layers,

Gulf of California North of 31° N. Latitude

	1972						1973					
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
All Stations												
Surface	--	29.3	--	26.2	19.4	13.9	15.3	16.2	--	18.7	20.6	25.0
5 m	--	29.1	--	26.4	19.5	15.8	15.8	16.2	--	18.6	19.8	24.3
10 m	--	29.1	--	27.5	20.2	16.8	16.2	16.3	--	18.5	19.6	23.1
20 m	--	--	--	--	--	--	16.5	16.3	--	18.3	19.0	22.0
25 m	--	--	--	--	--	--	16.9	16.3	--	--	18.8	21.7
Sea Stations												
Surface	--	29.2	--	--	21.6	17.6	16.9	17.0	--	18.4	20.1	23.8
5 m	--	28.8	--	--	21.5	17.7	16.8	16.4	--	18.4	19.4	23.3
10 m	--	28.9	--	27.7	21.3	17.6	16.6	16.3	--	18.4	19.2	22.7
20 m	--	--	--	--	--	--	16.6	16.3	--	--	18.9	21.8
25 m	--	--	--	--	--	--	16.9	16.3	--	--	18.6	21.4
Delta Stations												
Surface	--	--	--	25.9	18.8	12.1	13.9	15.4	--	18.7	21.2	26.7
5 m	--	--	--	--	18.9	14.7	14.6	15.6	--	18.4	20.4	26.6
10 m	--	--	--	26.9	19.7	15.6	14.9	16.0	--	18.2	20.3	--

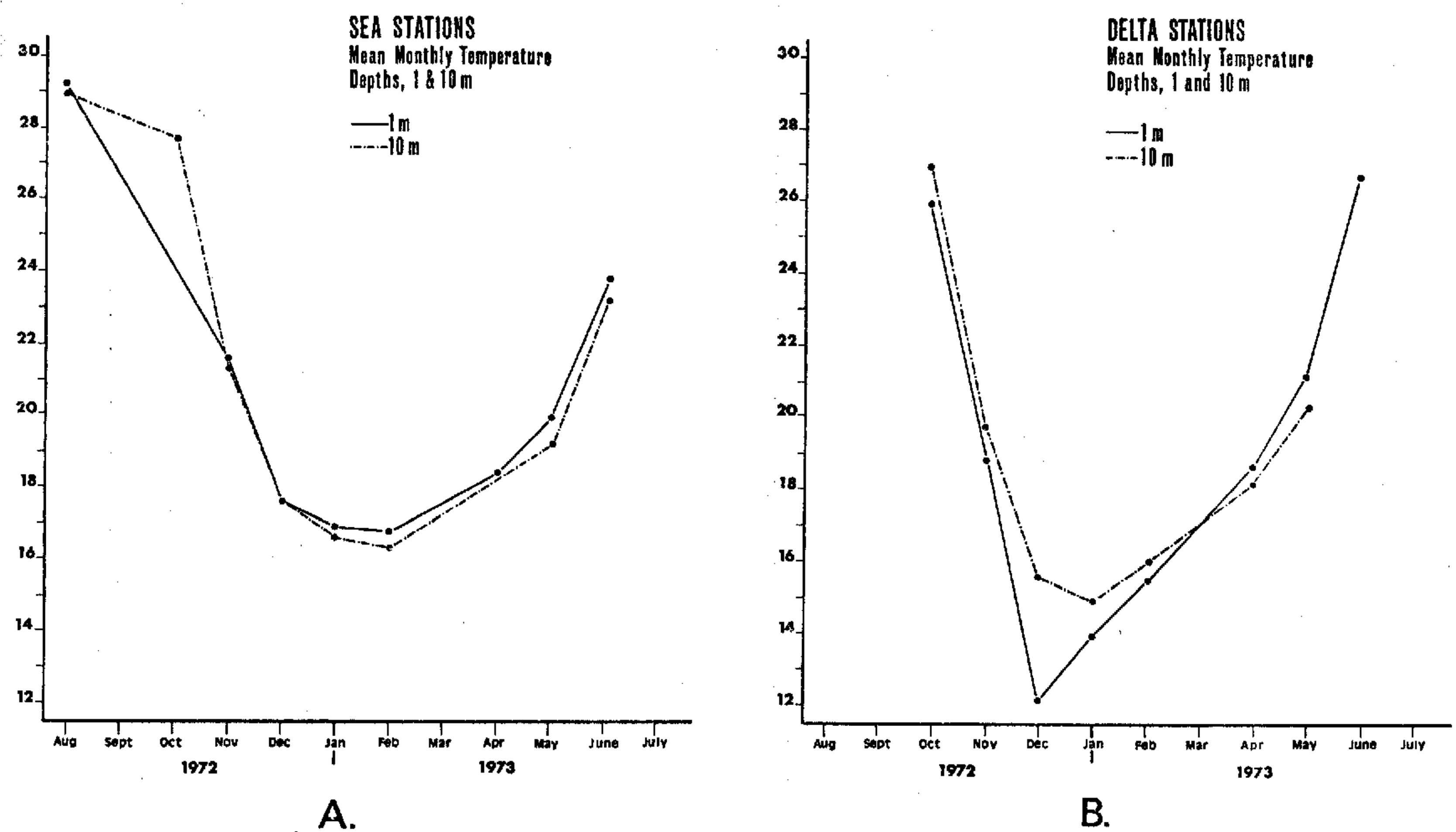

Figure 17. Mean Monthly Water Temperatures at Surface and 10 Meters: A.- Delta Stations; B.- Sea Stations.

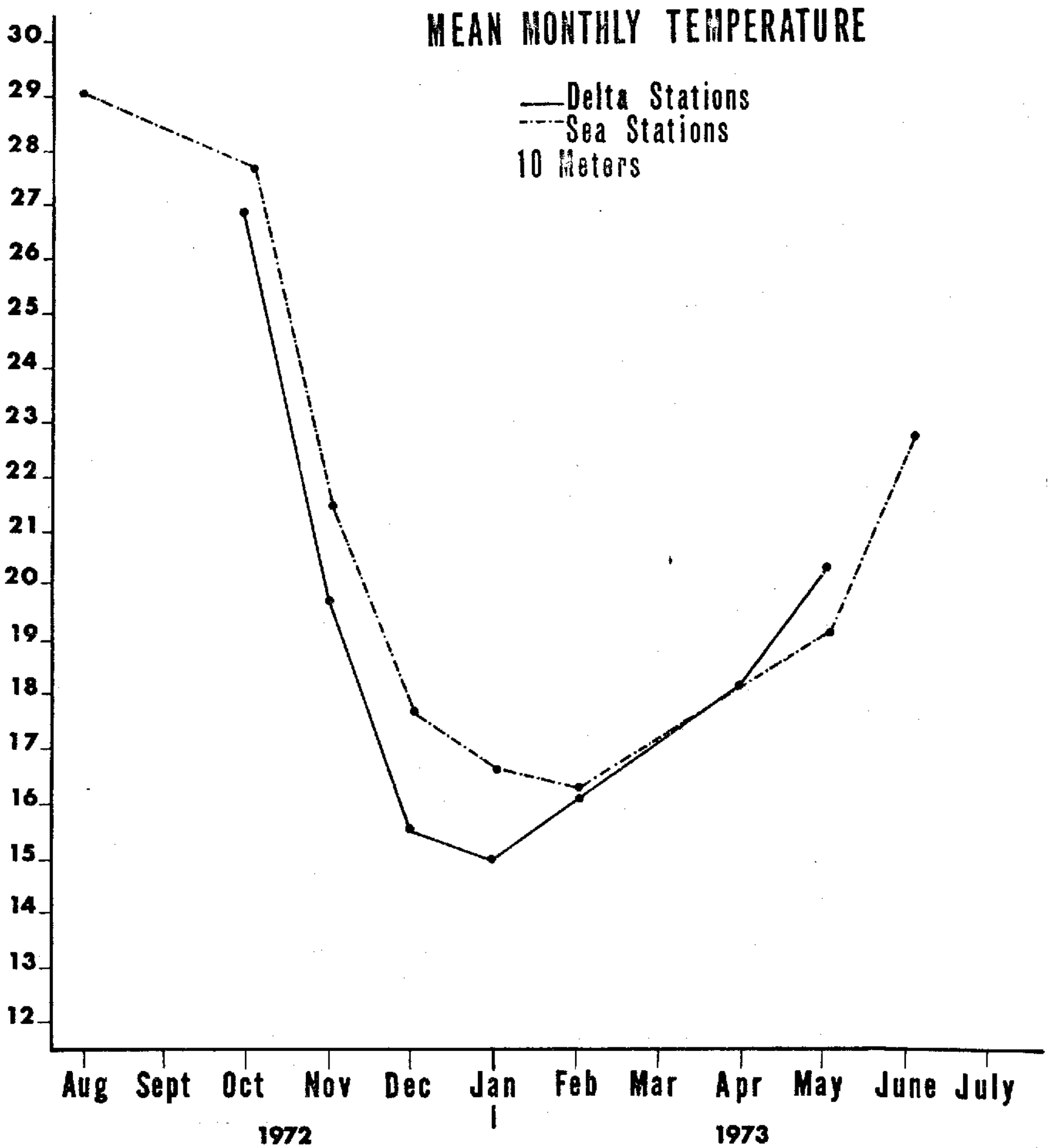

Figure 18. Mean Monthly Water Temperatures at 10 Meters - Delta Stations and Sea Stations Compared.

1. That Sea stations exhibit a different seasonal cycle than do the more shallow Delta and Shore stations.
2. Only in the months of August and February are temperatures for Sea stations approximated by near-shore measurements.

Comparison of observed sea surface temperature with that recorded at the Puerto Peñasco marine laboratory (see Table 10) through the period 1971-1973 is favorable. In Figure 19 are graphed the monthly means of the laboratory data and the monthly means of the Shore station subgroup; the single monthly observation of sea surface temperature of the station nearest the laboratory, station number A1 (see Figure 9), is also represented.

The plots of sea surface temperature from station A1 differ within the expected range due to diurnal variation. The difference between Shore means and the means from Puerto Peñasco are due to bias introduced by the numerous Delta stations included in the Shore subgroup; these have already been shown to exhibit a greater mean annual range.

Table 10

Comparison of Mean Monthly Sea Surface Temperatures from

Puerto Penasco, 1971-73 with Observations at Near-Shore Oceanographic Stations.

		July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Marine Laboratory	1971	29.0	29.4	28.2	22.3	18.1	16.0	12.1	14.3	14.4	18.0	20.4	24.8
(Monthly Means)	1972	29.1	29.1	28.6	25.6	19.4	15.7	13.4	13.8	17.5	18.4	22.3	26.2
	1973	--	--	--	--	--	--	13.9	15.4	15.7	17.8	22.7	25.6
Station A1 (Single Observation)		--	29.2	--	26.0	20.2	17.0	16.2	16.4	--	--	20.8	23.6
Shore Stations (Monthly Means)		--	29.5	--	26.2	19.1	13.2	14.3	15.8	--	18.8	20.9	25.9

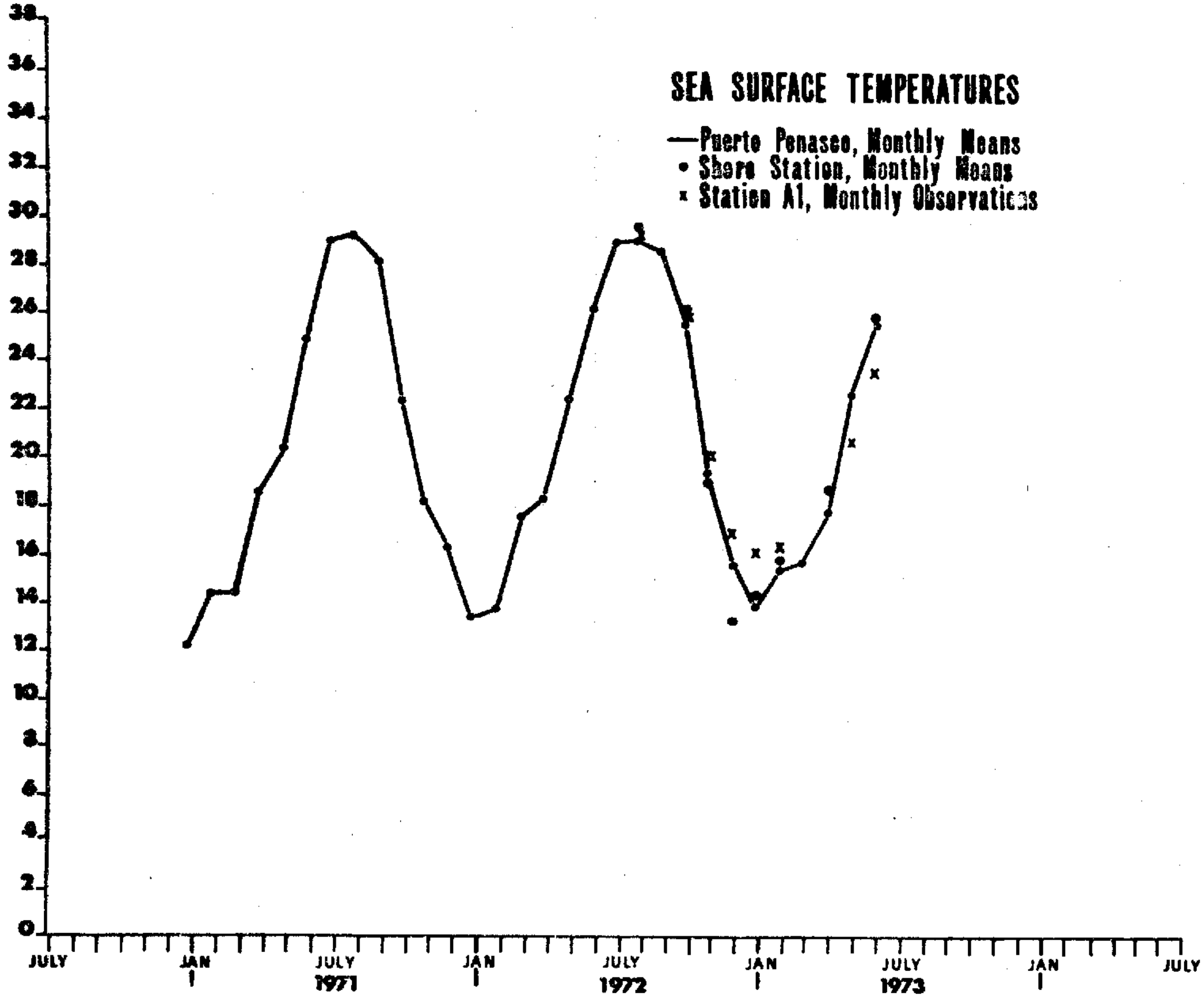

Figure 19. Sea Surface Temperatures, Puerto Penasco Marine Station and Oceanographic "Shore" Stations.

b. Salinity

The monthly mean surface salinities for the total area and Sea and Delta subgroups are given in Table 11. Included also are the mean maxima and minima for each month. The minimal salinities for both subgroups occur in January and the maximal salinities occur in the summer months, represented by June in the Table; unfortunately, salinity measurements made during the August cruise are suspect due to instrument malfunction and are not presented. The mean annual range varies from 1.3 $^{o}/oo$ to 2.5 $^{o}/oo$ for the Sea and Delta subgroups respectively. Rosenberg's data (1969) from Puerto Penasco are in general agreement though he underestimated the salinities which commonly occur in the Delta area. The variation within the months is from 0.5 - 2 $^{o}/oo$ for the Sea and Delta subgroups respectively. Apparently, much of the mixing that exchanges the water of the northern Gulf occurs in the Delta area where the hypersaline water from the tidal channels and flats meets the less saline water circulating upward from the south.

Mean salinities of the near-surface layer are given in Table 12 for two subgroups, Delta and Sea stations, and for all stations as a whole. These data are displayed graphically for the 1 and 10 meter depths in Figures 20A and 20B. Generally speaking, salinity follows the same patterns discussed for the distribution of temperature in the near-surface layer. The warm temperature fronts of Figure 16 are now replaced with fronts of decreased salinity (Figure 21).

The buoyancy of the warm less saline water is especially apparent in the surface map for January showing the tongue of low salinity water moving northward along the Sonoran coast.

Both Roden and Rosenberg state that salinities generally range between 35-36 $^{o}/oo$ at the 10 meter level. The curve plotted in Figure 20A indicates that the salinity was about 0.5 $^{o}/oo$ greater than this, on the average, throughout the seasonal cycle. Also, isohalines published by Rosenberg (1969) for April 1957 and 1956 are not in agreement with the observed April means; one possible explanation is that very few stations were sampled during the April cruise and the data are from stations bordering on the Sonoran shore stations.

The salinity of the northern Gulf can be strongly influenced by rainfall. During October, 1972, a significant amount of rainfall occurred in the northern Gulf area; UABC had scheduled a cruise for the northern Gulf and fortuitously was able to observe its effects on this area. Salinities along both the Sonoran and Baja California coastlines were reduced from 0.3 - 0.4 $^{o}/oo$ with respect to salinities observed in the middle of the Delta area. The effect was especially pronounced near the numerous small esteros (Alvarez, 1973). No trace of the reduced salinities remained by November.

Table 11

Mean Surface Salinity

Gulf of California North of 31° N. Latitude

	1972			1973					
	July-Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
All Stations									
Mean Surface Salinity	--	36.3	36.5	36.0	36.5	--	37.4	37.1	37.6
Mean Minimum	--	35.8	35.9	35.5	35.9	--	36.4	36.5	36.7
Mean Maximum	--	36.9	37.3	36.9	37.1	--	38.5	38.2	39.5
"Sea" Stations									
Mean Surface Salinity	--	35.9	36.1	35.6	36.5	--	36.8	36.7	36.9
Mean Minimum	--	35.7	36.0	35.4	36.3	--	36.6	36.5	36.6
Mean Maximum	--	36.2	36.2	35.9	36.7	--	37.2	37.1	37.0
"Delta" Stations									
Mean Surface Salinity	--	36.4	36.7	36.3	36.6	--	37.7	37.7	38.8
Mean Minimum	--	35.7	36.0	35.6	35.6	--	36.6	37.1	38.3
Mean Maximum	--	37.0	37.3	37.2	37.3	--	38.6	38.9	40.1

Table 12

Mean Salinities of Near-Surface Layers,

Gulf of California North of 31° N. Latitude

	July-Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
All Stations									
Surface	--	36.3	36.5	36.0	36.5	--	37.3	37.1	37.6
5 m	--	36.3	36.2	35.8	36.5	--	37.1	36.9	37.3
10 m	--	36.2	36.0	35.7	36.5	--	36.8	36.8	36.9
20 m	--	--	--	35.7	36.5	--	36.4	36.8	36.7
25 m	--	--	--	35.6	36.5	--	--	36.8	36.6
"Sea" Stations									
Surface	--	35.9	36.1	35.7	36.5	--	36.9	36.7	36.9
5 m	--	36.0	35.9	35.6	36.5	--	36.9	36.7	36.9
10 m	--	36.0	35.9	35.6	36.5	--	36.8	36.7	36.9
20 m	--	--	--	35.6	36.5	--	--	36.7	36.9
25 m	--	--	--	35.6	36.5	--	--	36.7	36.7
"Delta" Stations									
Surface	--	36.4	36.6	36.4	36.7	--	37.7	37.7	38.7
5 m	--	36.4	36.1	36.1	36.6	--	37.4	37.4	38.7
10 m	--	36.3	36.0	36.0	36.4	--	37.0	37.2	38.5

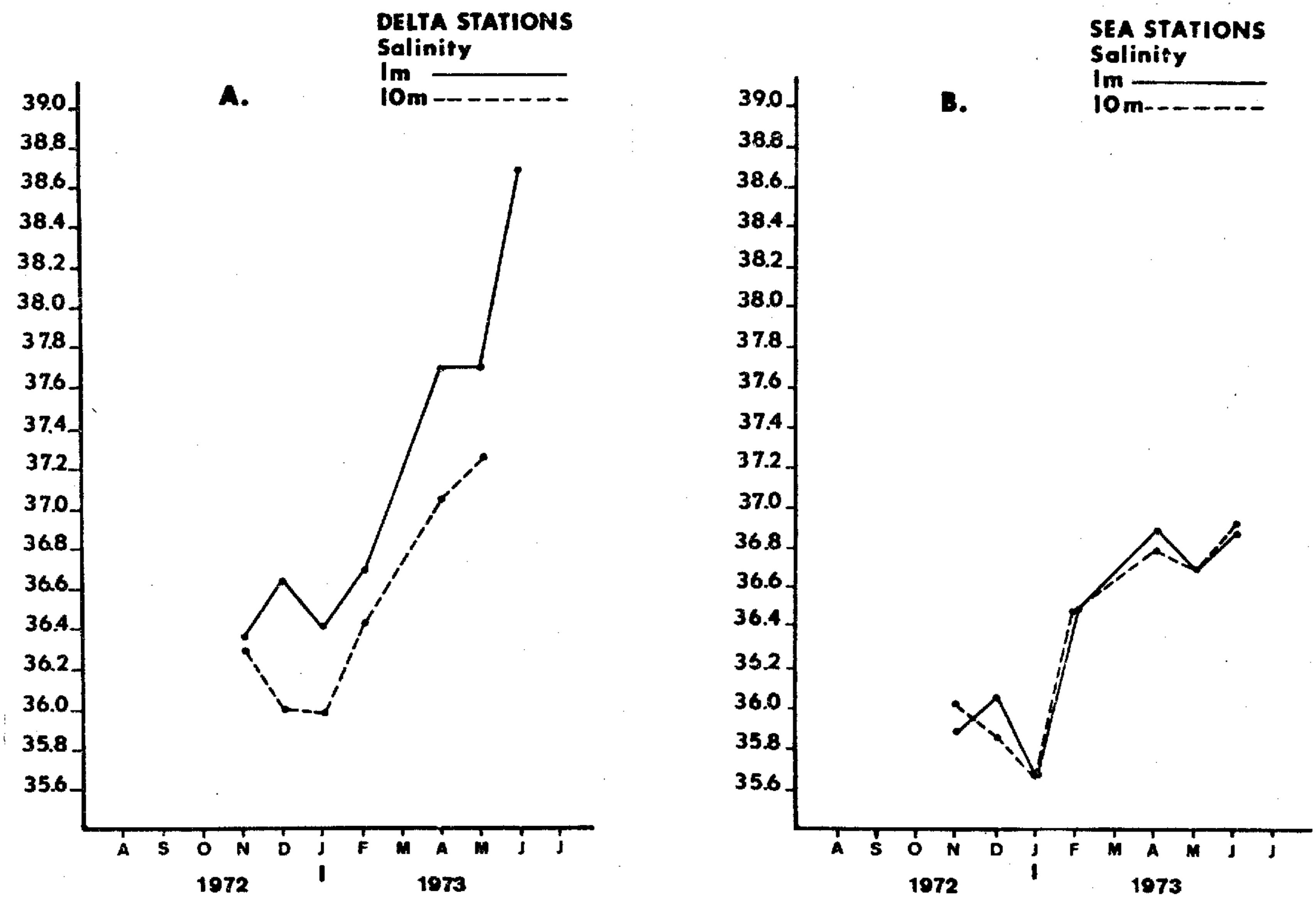

Figure 20. Mean Monthly Salinities at 1m. and 10m. Depths;
A.- Delta Stations; B.- Sea Stations.

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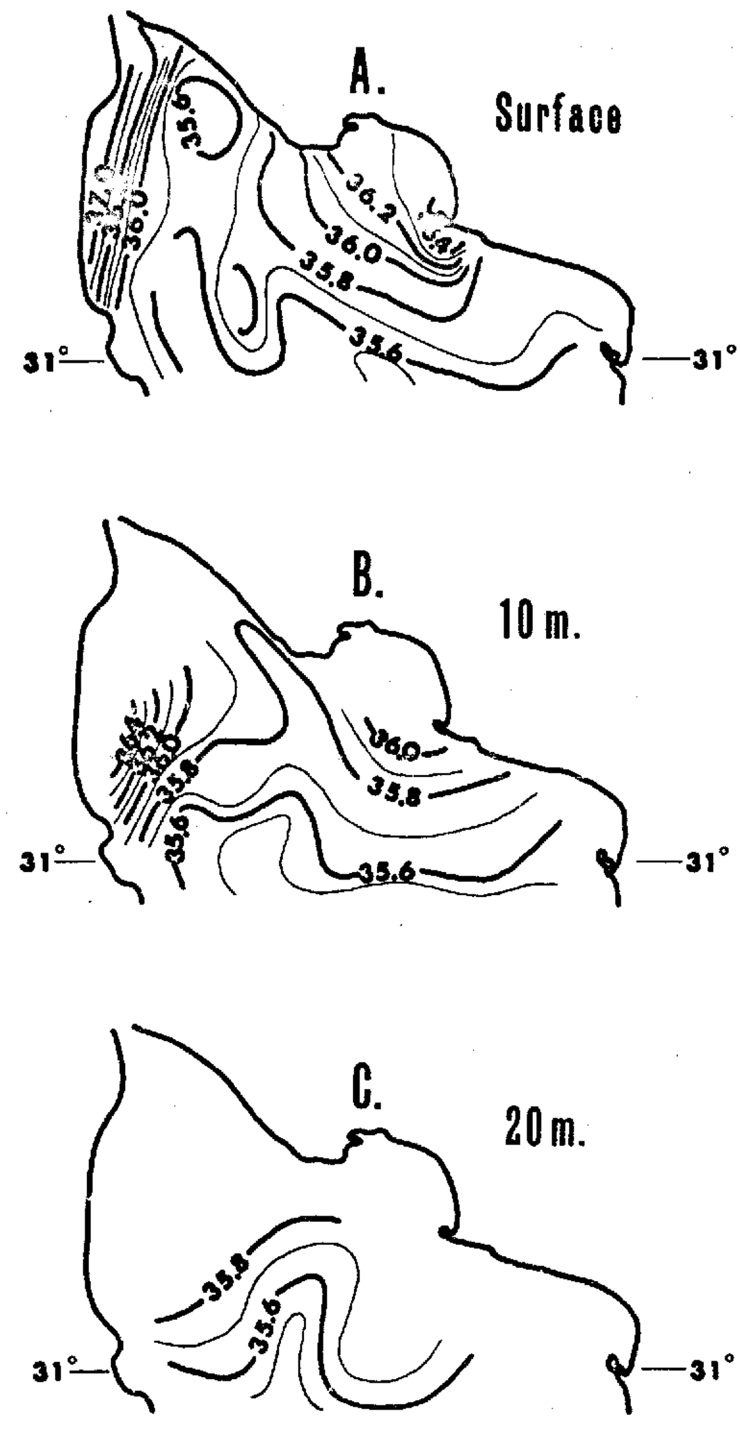


Figure 21. Isohalines for Northern Gulf of California, January, 1973: A.- Surface; B.- 10 Meter Depth; C.- 20 Meter Depth.

c. <u>Turbidity</u>

The turbidity of the northern Gulf of California has received little attention from oceanographers or biologists, and the literature contains few references on the distribution of suspended sediments in this interesting area. Because of the recent interest in the northern Gulf as a site for high-altitude and satellite remote sensing studies (Ross, 1969; Yost, 1970; LaViolette and Chabot, 1969) the turbidity of these waters has assumed an increased importance relative to other parameters.

Secchi depth and submarine photometer measurements were made for each oceanographic station visited on the 9 cruises mentioned above (Figure 13). In addition, ERTS-matched reflectance spectra from 1.5 meters above the water surface were obtained for some of the stations (Figures 23 and 24). These data served as "ground truth" for interpretation of the ERTS-1 imagery of the area and their interpretation in that capacity will be discussed in section IV of this report. Presented here is a general summary of turbidity conditions of the northern Gulf of California as observed during the period 1972-73. The point of view will be that of the marine biologist, and not of the optical oceanographer; the latter approach, utilizing submarine photometer data, is planned for a subsequent publication.

The most impressive single aspect of the turbidity of the northern Gulf is the extreme variation between the northern and southern stations. The Secchi disk turbidity measurements varied from 0.1 to 21.9 meters (0 - 72 feet) within a single cruise. There is also a great deal of east-west variation, as pointed out earlier by Gayman (1969) and Austin (1972).

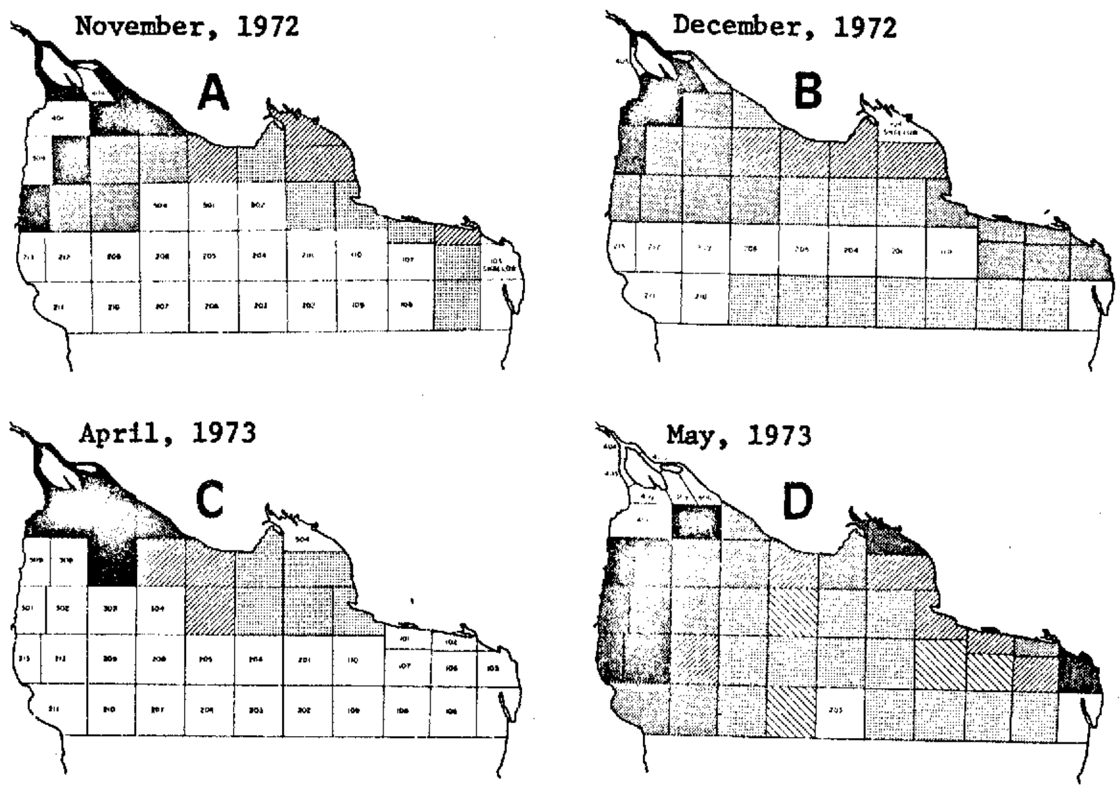
In order to deal with the high degree of variation within the data, the natural logarithms of the Secchi depths (in feet) were determined. These figures were then scaled into 7 categories and turbidity maps were prepared by dividing the northern Gulf into regular spatial units, each represented by one of the standard oceanographic stations shown in figure 9. The choice of 7 levels was determined by a simplified cluster analysis which indicated two strong classes (levels 6 and 4), two extreme classes, and three intermediate classes. Monthly turbidity maps created by this method are displayed in Figure 22; in addition, an "average" turbidity map for all months is shown, based on the coded average Secchi depth (Figure 22-J).

A qualitative description of the turbidity levels mapped in Figure 22 is presented in Table 13, with the associated Secchi depth range. The description of water color is purely qualitative and is included to facilitate understanding for those who are unfamiliar with this area; the description of level 1 turbidity is not exaggerated.

As can be seen on the maps in Figure 22, the Delta subgroup of stations (refer back to Figure 15-B) were generally associated with turbidity levels 1, 2 and 3, with the "D" (=400) stations always showing maximum turbidity, or

Table 13. Observed Turbidity Levels in the Northern Gulf of California with Associated Secchi Depth Range and Description. All suspended sediment concentrations are interpreted from Thompson (1968).

Level	Secchi Depth Range	Description
1	d<1 ft 0.3 m	Water extremely turbid with visible surface whorls of suspended mud against an opaque reddish-brown color. Usually associated with spring tidal currents and found most often near Isla Montague. Suspended sediment conc. as high as 10,600 ppm. Approximately 25% of water sample volume settles out within 30 minutes.
2	1-2 ft 0.3-0.6 m	Water very turbid with uniform reddish-brown opaque color. Associated with strong tidal currents of all tidal series. Common in all "D" stations when not in a spring tide series. Suspended sediment concentration 100-500 ppm.
3	2-3 ft 0.6-1.0 m	Water very turbid with opaque yellow-brown color. Associated with tidal currents moving over the shallow sedimentation plain and over shoals. Suspended sediment concentration 5-100 ppm.
4	3.5-8.0 ft 1.0-2.5 m	Water turbid with translucent yellow-brown to yellow-green color. Associated with 10-15 m depths over the sedimentation plain.
5	8.5-17.0 ft 2.5-5.2 m	Water turbid with translucent yellow-green to green-blue color. Associated with Sonoran shore stations or transition areas between Delta and Sea stations.
6	17.5-33.0 ft 5.2-10.0 m	Water clear with blue-green color. Associated with depths greater than 15 m.
7	d>33.5 ft 10 m	Water very clear with deep blue color. Usually associated with depths greater than 40 m and occurring only in the Sea station subgroup.


November, 1972
A
December, 1972
B
April, 1973
C
May, 1973
D

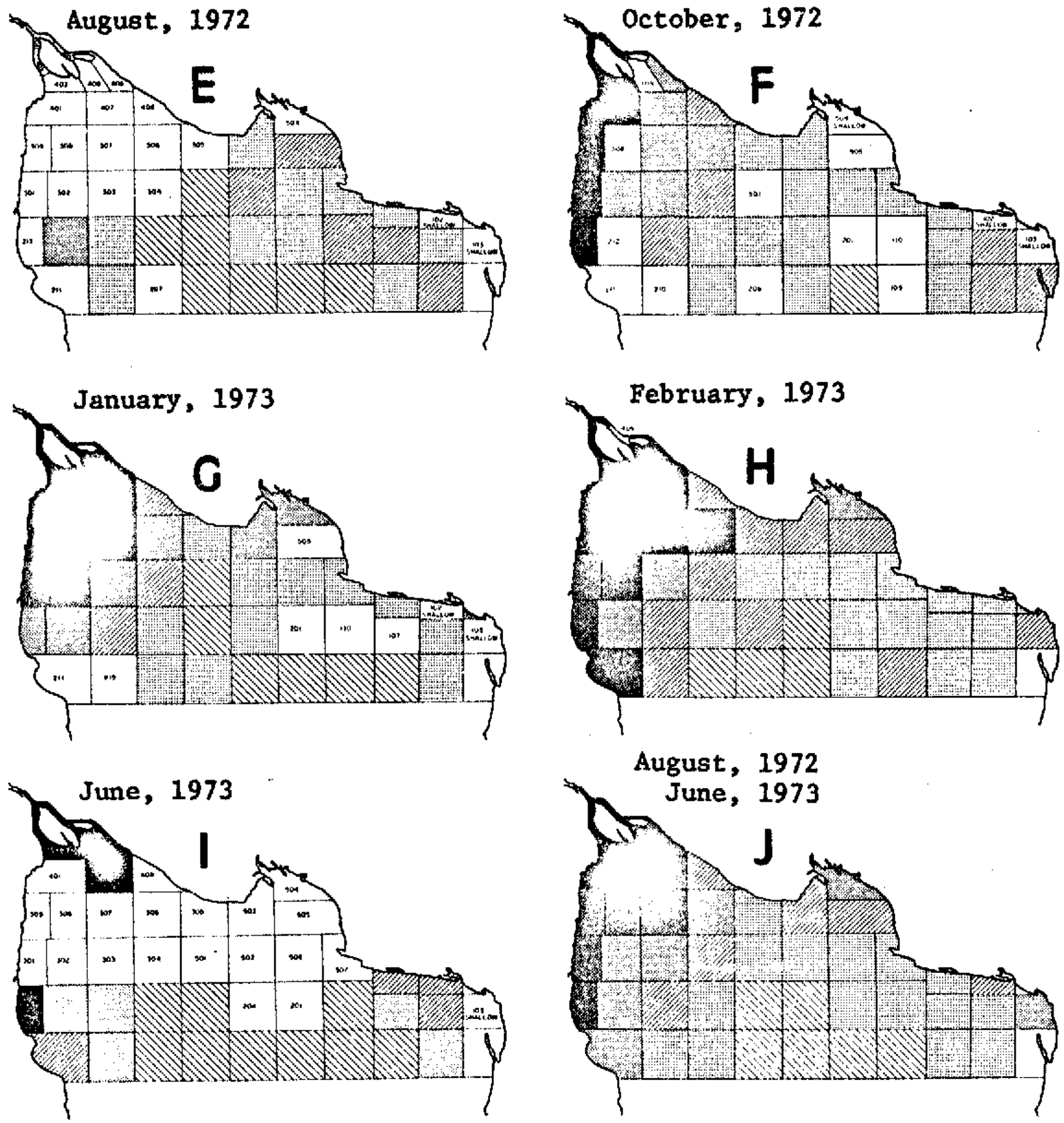


Figure 22. Turbidity Levels, N. Gulf of Calif., by Months.

level 7. The "C" (=300) stations of the Delta subgroup alternated between levels 2, 3 and 4. A north-south pairing of "D" and "C" stations occurs, with the trend showing association of levels 1, 2 in the "D" group with levels 2, 3 in the "C" group, etc., demonstrating a gradient of decreasing turbidity southward along the NW-SE axis of the Delta subgroup. While this is generally true for the central stations oriented along the NW-SE axis of the Gulf, the stations immediately adjacent to the Baja Californian and Sonoran shores are relatively stable in turbidity throughout the year. Sonoran shore stations D8 (408) and C5 (305) were always more clear than the remainder of the Delta stations; their levels were usually 5 and 6, respectively. The Baja Californian shore stations, extending southward to San Felipe, almost always exhibited level 3 turbidity. These observations are in general agreement with those of Gayman (1969).

The south-central stations, containing most of the Sea station subgroup (see Figure 15-A), were associated most commonly with turbidity levels 6 and 7. It is unclear from ship-based observations what factors were influencing the alternation between these two levels (but see section III-7-d following, and section IV-3). Whether these "point-in-time" measurements may reliably be used to represent general, long-term trends, or whether they have value only as rough indicators and as means, remains to be determined. There is a particular apparent inconsistency between the low August, 1972 turbidity measurements made by ship and the general surface turbidity which would be predicted by the model described in section IV-c.

The Sonoran shore stations of Bahia de Adair (503, 504, 505), Puerto Peñasco (507) and Bahia San Jorge (101-3, 106, 107) were highly variable, exhibiting levels 4, 5 and 6. These areas appear to circulate internally as well as being influenced by the central water mass; the stations closest to the shores, often too shallow to obtain a non-bottom reading, contribute sediment to the rest of the stations within the local sub-cell. Thus, though they show different readings, if the shore-bordering stations within the two bays concerned show levels of 4, then the outer stations show levels of 5, and similarly for levels of 6 and 7.

The general comments presented above are borne out by the map of average Secchi depths observed within the period. This map (Figure 22-J) has a higher predictive value from an experimental point of view. A number of interesting future experiments could be designed according to the tendencies shown therein with regard to the distribution of turbidity levels 1 through 7.

Austin (1972) reported on turbidity measurements made in the northern Gulf during March, 1971. He found that, for stations sampled along latitudes 31° 00' and 31° 20' N., turbidity layers occurred, generally taking the form of a layer of clear water overlying a layer of turbid water, sometimes with four alternating layers distinguishable. Our findings are in general agreement with this, but one important qualification is called for: Such findings should not be extrapolated to the north of 30° 20' N. too freely, and then only with caution should vertical turbidity structure be postulated for the stations near the mouth of the Colorado River.

d. Summary of surface observations

The distributions of temperature, salinity and turbidity discussed in the previous sections are notably coherent. In winter fronts of clear, warm, low saline water come up from the south and disappear off the coast of Sonora near stations E1 and C5. On the Baja California side, the cold, turbid and highly saline waters extend further to the south. Our observations apply only to the near-surface layer, and since summer data are lacking, only to the winter months. With these qualifications in mind, a counterclockwise circulation pattern is clearly indicated from the near-surface distributions of temperature, salinity and turbidity. This is in agreement with Thompson's near-shore tidal current measurements and with his work on sedimentation, turbidity and tidal-flat topography (1969). It is in apparent conflict with the winter surface current pattern predicted by the model described in section IV-3 (Figure 27-A). It is unfortunate that adequate shipboard data for the summer season are lacking. The presence of two periods of vertical mixing in at least the upper 25 meters of water (section III-7-a), occurring in opposite portions of an essentially two-season environment, seem to indicate that two systems exist. The northern Gulf circulation is probably more complicated than a simple counterclockwise system and complete data from both seasons are needed.

The turbidity distribution appears to be somewhat more complicated, and the layers found by Austin and observed by us during submarine photometer measurements indicate that at least part of the suspended matter of the delta waters reaches all the way to 31° north latitude in near-surface waters (although not at the actual surface). Fishermen who longline in these very deep waters know the bottom to be entirely of fine mud. One can readily visualize flows of winter-chilled water, heavily laden with suspended matter, moving southeastward along the bottom of the northern Gulf and depositing sediment. It would appear that these turbid bottom flows do not become heavily involved with the convective mixing processes described earlier. This would be possible if they followed the narrow trench reported by Thompson (1969) which runs from the tip of Isla Pelicano to the northern End of Wagner Basin. It is over this same channel, but in the near-surface layer, that waters from the central Gulf are delivered in their movement up the northern Gulf. The shape of the channel and its decreasing depth with extension northward, would tend to bring these waters to the surface in fronts of differential salinity and temperature.

The hypothesis that we wish to put forth is that the above channel is the main circulatory pathway for exchange of the northern Gulf of California waters. The southern central Gulf waters flow up this channel until they are forced to the surface by decreasing depth; convective mixing occurs over this channel and continues northward, while the counter-clockwise circulation tends to carry the surface waters derived from the extreme northern Gulf Delta area southward along the coast of Baja California. An oceanographic vessel, equipped with deep water gear should be able to confirm the presence of the flow up this channel. Measurements in both winter and summer would be required.

8. Analysis of Historical Data

After a search of the literature, all physical oceanographic data collected previously in the Gulf of California north of 29° 40' North latitude were selected for comparison with data collected in this investigation. These data are displayed in Table 14 as the mean monthly temperature and salinity for the year collected.

References for oceanographic data outside the area of consideration are within the bibliography and all the data discussed below are cited in section VIII. This method was selected to facilitate a literature search in this area for those interested in the northern Gulf of California physical oceanography, both north and south of our arbitrary 29° 40' North latitude line. The references are as complete as possible.

The data in Table 14 show no particular trends and appear to be well within the expected range of values for each month. In particular, no significant increase in salinity during the period 1939-1971 is apparent. This is in agreement with the conclusions of Rosenberg (1969). Further pursuit of the hypothesis that the salinity of the northern Gulf of California has increased due to interruption and diversion of flow of the Colorado River does not seem warranted due to the lack of available data for comparison and to the absence of trends of increasing salinity within the existing data.

One notable point concerning Table 14 is the total range of measurements for the months of March and April. This implies that the seasonal curve maintains a consistent shape and is displaced forward or backward within the cycle. For the two major seasons, winter and summer, this would have little effect. For the months of greatest change, October and March, the displacement could have the effect seen in Table 14.

In general, our monthly means are consistent with those measured previously from the site and no indications of significant abnormality of the year sampled are present.

Table 14

Summary of Physical Oceanographic Data, North of 29° 40', Prior to 1972

	Monthly Mean Temperature (°C) March	April	June	Aug	Sept	Monthly Mean Salinity March	April	June	Aug	Sept
1889(1)										
Surface	19.22									
1	-									
5	-									
10	-									
20	19.15									
20+	17.20									
1939(6)										
Surface	16.07					35.36				
1	-					-				
5	-					-				
10	15.22					35.36				
20	14.54					35.35				
20+	14.16									
1956(2,6)										
Surface		17.88					35.65			
1		-					-			
5		-					-			
10		17.89					35.64			
20		16.66					35.42			
20+		15.83					35.35			
1957(6)										
Surface		20.01	25.13	29.87			35.47	35.57	35.42	
1		-	-	29.67			-	-	35.32	
5		-	-	-			-	-	-	
10		19.65	23.72	30.03			35.52	35.50	35.52	
20		18.10	22.10	29.62			35.36	35.37	35.37	
20+		15.85	1947	28.03			35.26	35.31	35.33	
1959(3,6)										
Surface		20.36					35.56			
1		19.90					35.55			
5		21.65					35.64			
10		20.04					35.54			
20		18.37					35.49			
20+		16.61					35.39			
1962(4)										
Surface	15.57									
1	-									
5	15.58									
10	15.68									
20	15.79									
20+	15.78									
1971(5)										
Surface					30.04					36.15
1					30.24					35.65
5					29.94					35.95
10					29.77					35.98
20					25.56					35.48
20+					25.56					35.48

1. Source: Townsend, 1901
2. Source: Reid and Arthur, 1965
3. Source: Reid and Arthur, 1965
4. Source: Anon, 1969 (Calcofi Data Report 12)
5. Source: Unpublished data from R/V Humboldt
6. Source: National Oceanographic Data Center, Computer Printout, Washington, D. C.

IV. ERTS IMAGERY ANALYSIS

(Dr. Larry K. Lepley, Arid Lands Studies, Univ. Ariz.)

The northern Gulf of California proved to be an ideal site for the use of satellite data in that: a) only a small proportion of the imagery suffered loss of detail from cloud cover, b) water masses were usually separable by their distinctly different turbidities, and c) the Gulf waters are extremely dynamic, showing high rates of flow in both tidal and seasonal components. A full year's synoptic observation through ERTS-1 imagery, correlated with in situ point measurements from aboard ship, has made possible the synthesis of a seasonal thermal dynamic model of the circulation of the waters of the northern Gulf (section IV-3). This model is here presented for the first time, not as the definitive answer to all questions about circulation in the northern Gulf, but as a first-stage conceptual rendering to be tested against observations and theoretical considerations. We will attempt to show how this model is depicted by the ERTS-1 imagery and will describe other phenomena not easily observable from conventional oceanographic data alone. The latter include: short internal waves, long-term current velocities upon which the higher tidal components are superimposed, and wind-driven surface layers.

1. Nature of the Data

Due to the wide variance in water clarity in the northern Gulf, imagery in all four MSS bands was useful, especially in negative format wherein the gray levels of the images were more suitable than in the positives. We received several sets of unsolicited dodged prints from Goddard Space Flight Center, and found these to be very useful because good contrast of both the suspended particulate matter in the water and of the adjacent bright desert regions was available in the same frame.

Appendix B lists the image identification numbers of the ERTS-1 imagery which we analyzed.

We collected ERTS-matched reflectance spectra from 1.5 meters above the water surface at oceanographic stations, using an Exotech four-channel radiometer made available by the Arizona Regional Ecological Test Site (ARETS) program. Figure 23A to 23C shows this data plotted as un-normalized reflectance spectra. Two readings were taken with each of the channels, one reading of downwelling incident radiation through a diffusing plate and the other of upwelling scene radiance over a 15° field of view. The ratios of these sets of readings in each of the channels were plotted without any attempt to normalize to 100% reflectivity. The oceanographic station numbers adjacent to these curves refer to station locations as shown in figure 9 of this report (section III-3). Other surface truth data used in our image interpretation, including Secchi disk measurements and turbidity and temperature profiles are described in sections III-2 and III-7.

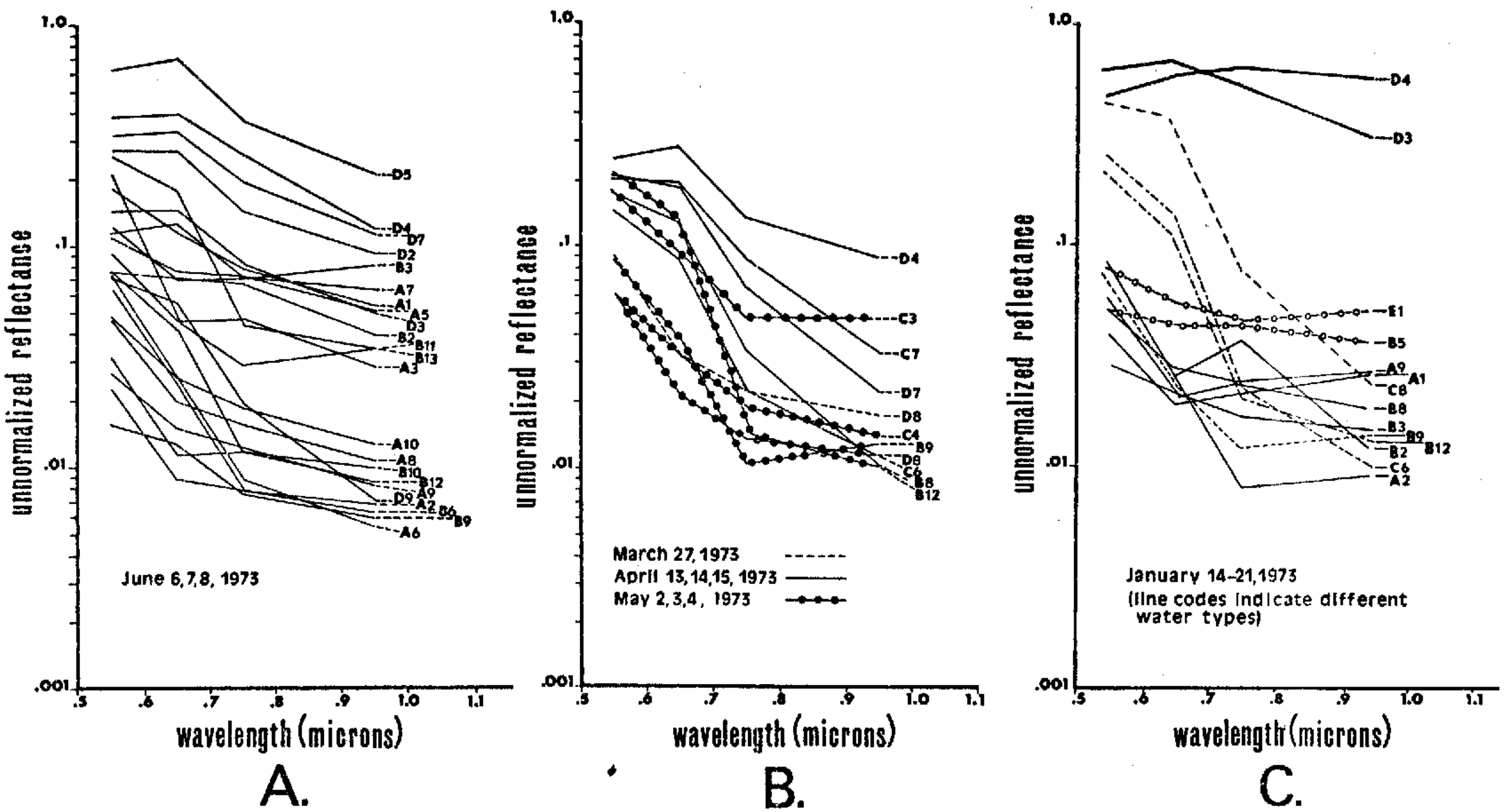


Figure 23. ERTS-Matched Reflectance Spectra from Oceanographic Stations, Northern Gulf of California.

2. Data Analysis Methods

By use of the known spectral properties of coastal sea water (Lepley, 1968; Tyler, et. al., 1970; Williams, 1970), we can make predictions as to the approximate thickness of the surface water layer in which or through which turbidity patterns are imaged in each of the four ERTS-1 MSS spectral bands. The depth of integration (penetration) is different for each of the four spectral bands and is different for each degree of turbidity in the uppermost water layers. .

Figure 24 is a diagram which can be used to estimate relative depths seen by comparing the imagery of the four bands. This figure is intended as a working tool and is based largely on Lepley's experience in multispectral photography and radiometry over shallow water. The accuracy of the curves is approximately one order of magnitude.

The appropriate curve A, B, C or D of Figure 24 can be chosen by comparison of the relative darkness of the water in the imagery in the ERTS-1 spectral bands. Curve D should be used where the water appears quite dark in all four channels; Curve C when the water appears dark in channels 5, 6, and 7, and light grey in band 4; Curve B where the water appears dark only in bands 6 and 7; Curve A where the water appears dark only in band 7.

Once the turbidity class A, B, C or D is established, an order-of-magnitude depth estimate of turbidity patterns can be made. For example, if two superimposed patterns are seen in type B water on a band 5 image, but only one of these is seen on the band 7 image, then we can say that the band 7 image shows the turbidity pattern of the upper 10 cm. surface layer, whereas the band 5 image shows this same pattern superimposed on a second pattern representing the 10 cm.- 100 cm. depth interval. Thus, we can use a comparison of the imagery in the available spectral bands for estimation of depths to back-scattering layers at various levels in the water mass.

From band 4 (green), we expect to see images through the first 3 centimeters to 30 meters of water, this large variance depending on water turbidity. The penetration depth estimation for this green light is the least predictable, due to the large influence of relatively small amounts of suspended particulate matter. The penetration of band 5 (red) in the northern Gulf may be expected to range from 10 centimeters to 3 meters, the variance being more restricted than that of the green band. Deeper penetration in highly turbid waters may be expected in band 5 than in any other band, even though it will have less penetration in clear water than will band 4. In band 6, the absorption properties of the water itself dominate, and the range of image perception is estimated to be from 3 centimeters to 30 centimeters. In band 7 the high absorptivity of water is almost entirely predominant; images of the surface layer from 1 to 3 centimeters are expected.

The spectral reflectance data taken at the oceanographic stations, when plotted as reflectance in one spectral band versus reflectance in another, were found to cluster especially well when band 4 was plotted against band 6 as shown in Figure 25A and when band 5 was plotted against band 7 as shown in Figure 25B. Two aspects of these plots are significant. The clusters representing the bodies of water that we considered likely to contain high biological content are located

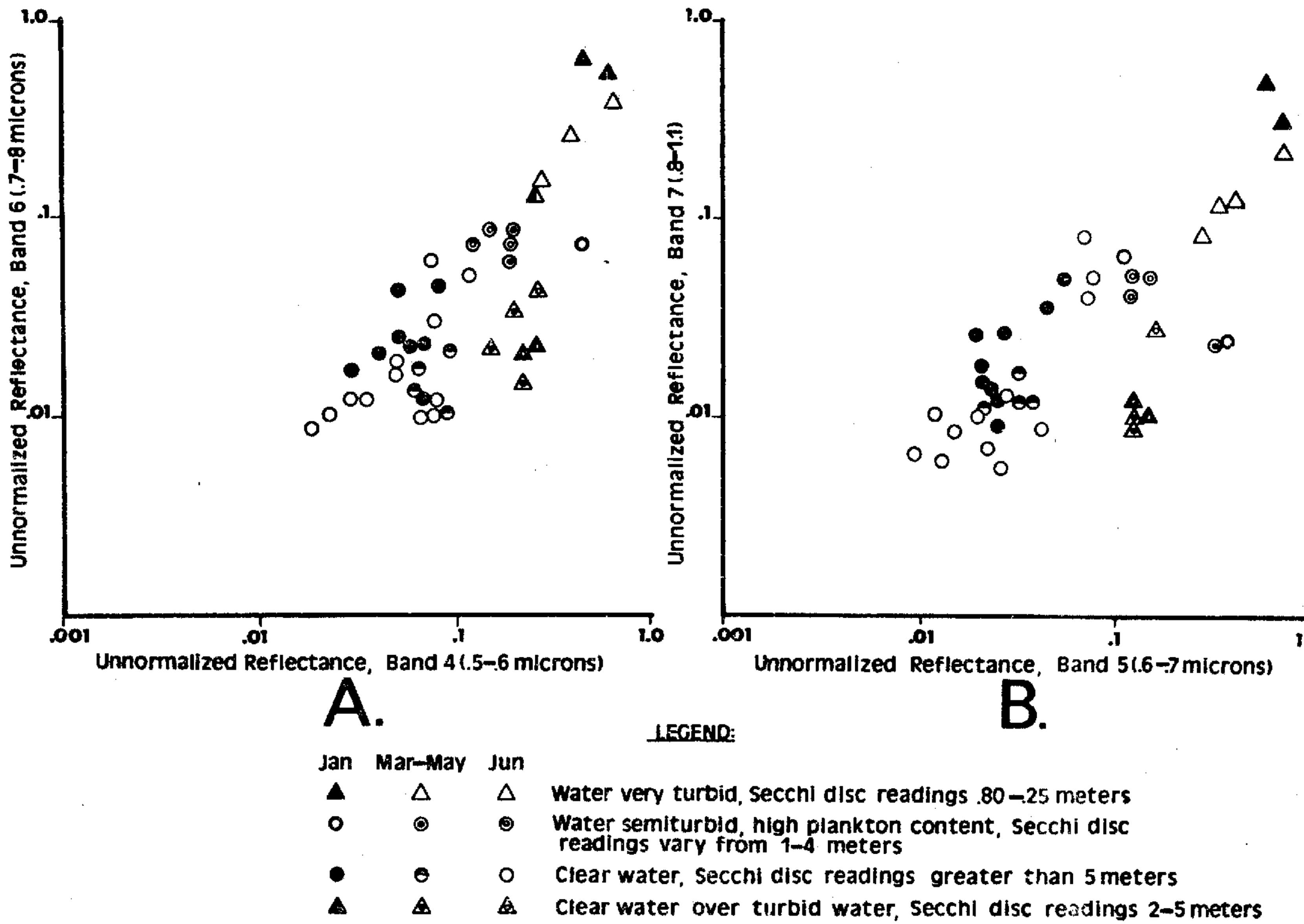


Figure 24. Penetrance of ERTS-1 MSS Spectral Bands, Northern Gulf of California.

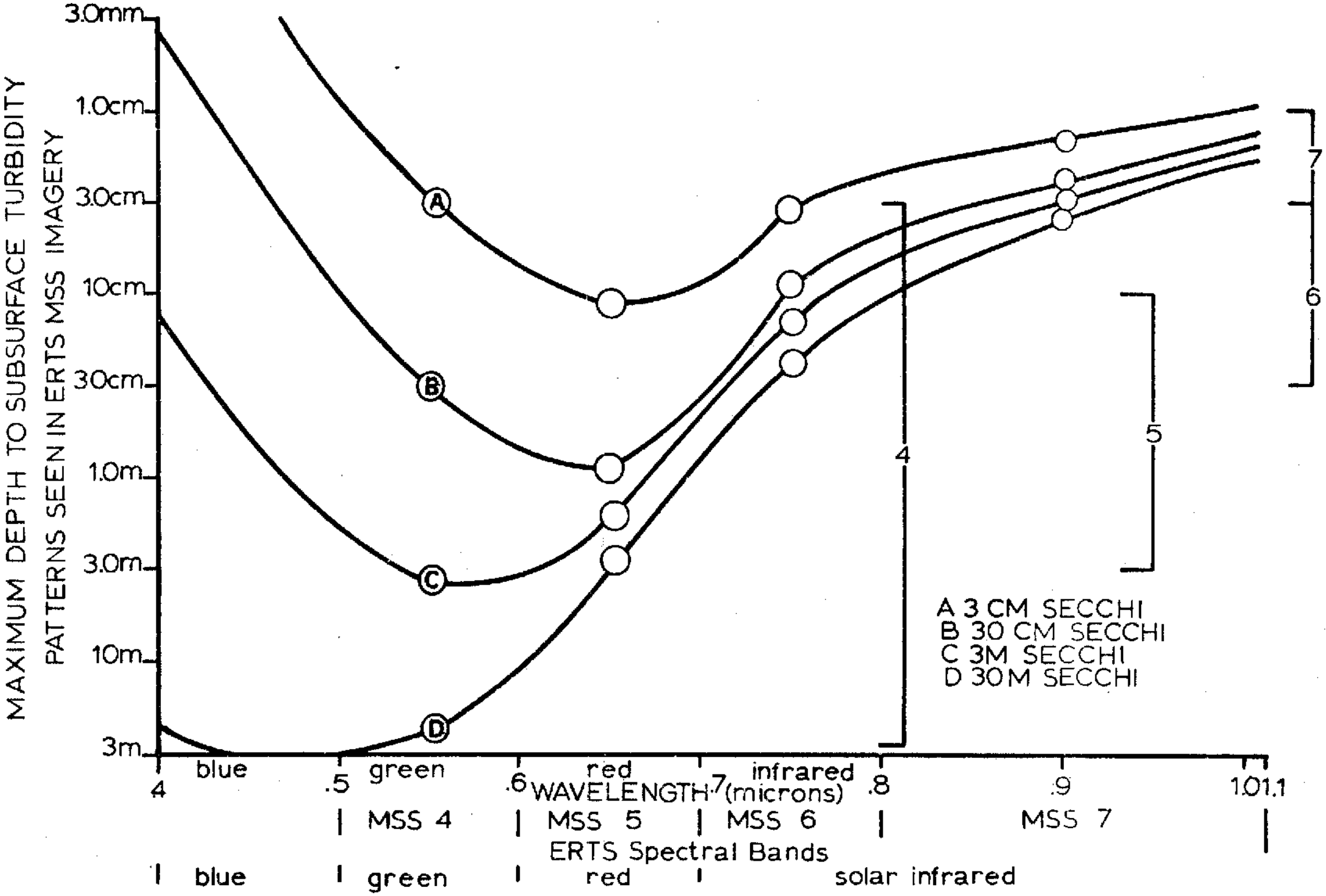


Figure 25. Band Plots of ERTS-Matched Reflectance Spectra from Oceanographic Stations, Northern Gulf of California.

in the areas corresponding to areas of intermediate turbidity, and it is also important to note that the reflectance spectra of layers of relatively clear water overlying turbid water are different from that of unlayered mixed water of any particular turbidity. This result implies that, with remotely sensed spectral data, mixed water bodies can be separated from stably laminated bodies of water. Our analyses of this spectral data, coupled with sub-surface measurements of Secchi disk and turbidometer readings taken by ourselves and by Scripps Institution of Oceanography (Austin, 1972) were indispensable in our spectral interpretation of the multi-spectral satellite data (See Figure 24.).

In the early summer imagery wherein the solar elevation was at or above 60 degrees above the horizon, surface glitter of direct solar specular reflection from the water surface obliterated the subsurface turbidity patterns. However, these glitter patterns were found to be useful in themselves, in that bands of varying water roughness would reconstitute, on the sea surface, an image of subsurface oceanographic phenomena which became apparent in the satellite imagery.

As an aid to analysis, various image enhancement procedures were used. The most effective procedure was rephotographing ERTS-1 imagery to higher contrast and better gray scale range. The use of the ARETS Videoscanning densitometer was helpful in the beginning stages of the investigation and has good potential for certain types of areal determinations (viz., square miles of tidal flats uncovered at any one stage of the tidal cycle).

We found that knowledge of tidal stage and of wind velocity and direction were frequently essential in interpretation of the imagery.

3. A Seasonal Circulation Model for the Waters of the Northern Gulf of California

Thompson (1969) calls attention to conflicting evidence on the circulation of northern Gulf waters, with his measurements in open water suggesting a general net circulation clockwise, but with measurements and other evidence along the coasts suggesting counterclockwise rotation. He points out that, in comparable situations (North Sea, Adriatic Sea), the rotary tidal circulation is counterclockwise, which is consistent with theoretical models (Defant, 1958). The final sentence of his report is: "Obviously, a thorough study of the current system in the northern Gulf is needed." Unfortunately, the seasonal timing of Thompson's observations are not known at the time of writing this report, but it seems at least possible that both his apparently conflicting sets of evidence might be correct and in accord with the model presented here.

Basic to the concepts presented in our model is the phenomenon of a relatively small arm of the sea with high tidal activity exposed to a strongly fluctuating desert climate. As pointed out in section III-6 (Analysis of Meteorological Parameters), the range between extremes of air temperature in this area is extraordinary, on diurnal, monthly, and seasonal bases. In the particular case of the northern Gulf of California, the usual relationship of terrestrial climates "dominated" by proximal marine environment may with some justification be considered to be reversed. We suggest here that major changes in the circulation pattern of the northern Gulf have their bases in the seasonal changes of the proximal terrestrial desert.

Our model is that of a seasonally-reversing heat engine in which the flow-lines have been curled into gyres by the Coriolis effect. Figures 26 & 27 show schematically the thermally-driven convection system, reversing between summer and winter situations, which we are suggesting. In the summer (April through October), the principal heat source for the engine is the well-flushed, shallow tidal waters of the Colorado River estuary. As shown in section III-7-a, these waters rise in temperature to at least 3° C. higher than the waters at 10 meters depth, 100 kilometers out in the main water mass (the heat sink). Auxiliary heating occurs along the Baja Californian and Sonoran shores. In situ measurements and the satellite images both indicate that the solar-heated water is sufficiently warmed to become, despite its sediment load, a buoyant layer which pulses with tidal cycles over the surface of the cooler Gulf waters. This blanket of warm, turbid water would be expected to lose its buoyancy as it spreads out over the Gulf and its temperature diminishes. Thus is formed a convection cell, with the warm, turbid surface layer moving southeastward, cooling and sinking with its load of suspended sediment and thereafter moving back in a compensatory subsurface circulation. The Coriolis force, in accordance with theory and comparable situations elsewhere (see above) deflects this surface stream to the right as it moves down into the main area of the upper Gulf, and a major counterclockwise surface gyre is formed around a center of downwelling, cooled water. Figure 26.-A represents surface flow in summer according to this model, Figures 26.-C and 26.-D show the flow along longitudinal (roughly, northsouth) and transverse (roughly, east-west) sections. The points of downwelling in the sectional diagrams coincide with the centers of the gyre in the main diagram. Figure 26.-B represents compensatory subsurface movements in accord with Coriolis effect and physical oceanographic theory. This pattern

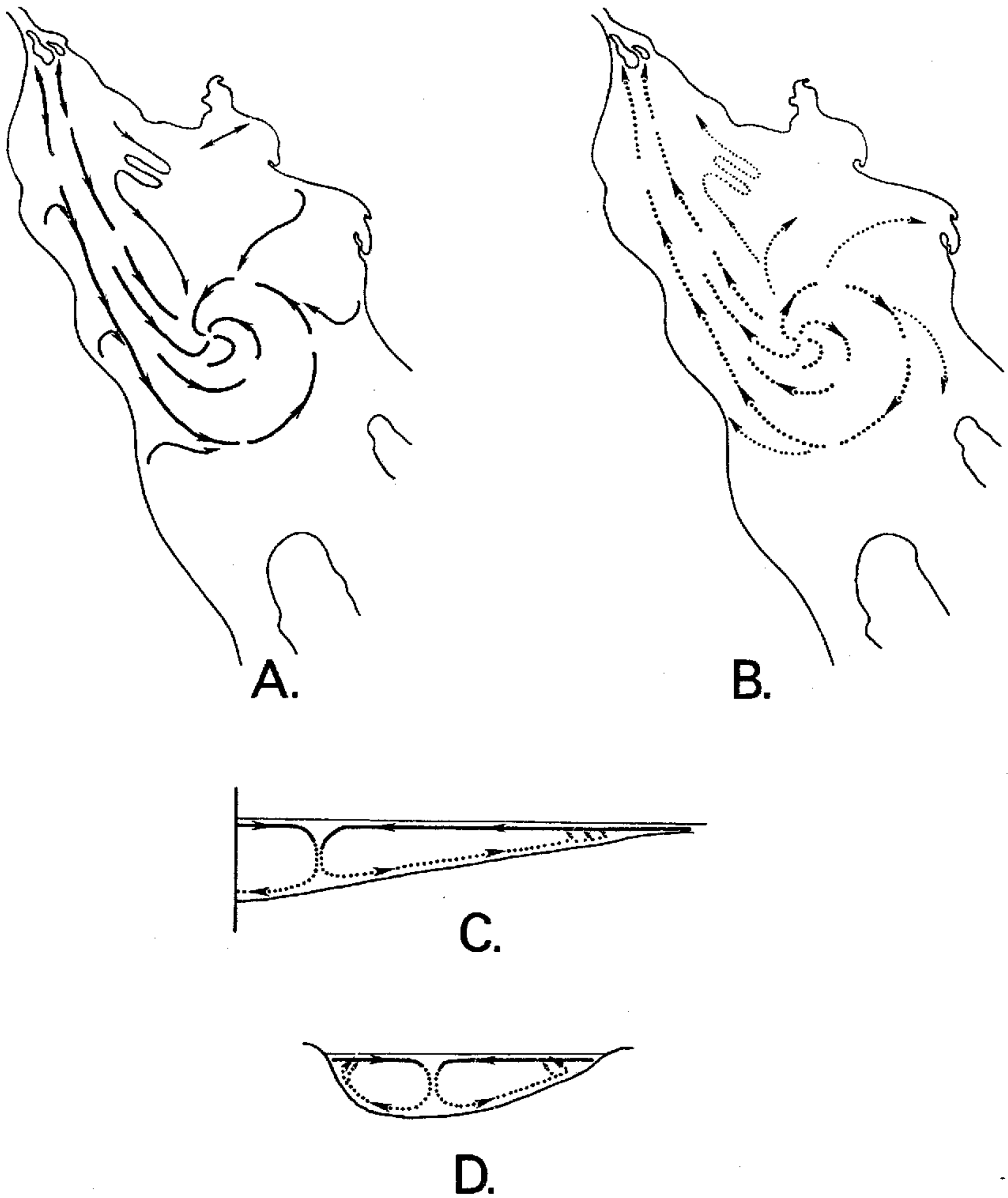


Figure 26. Thermal Dynamic Model, N. Gulf of Calif. - <u>Summer</u>: A.- Surface Circulation; B.- Bottom Circulation; C.- N-S Section; D.- E-W Section.

would produce areas of upwelling at points along the coast with offshore drift to complete the cell.

The winter heat engine (December through February) is completely reversed. The estuarine (and coastal) water is refrigerated to as much as 5° C. cooler than the water in the center of the upper Gulf, which latter now serves as the heat source. In this case, the chilled, turbid stream leaving the Colorado estuary on each ebb tide would be expected to dive beneath the residual waters and follow the shallow bottom southeastward (Sverdrup, 1941, also postulated convectional flow of cooled waters from the Colorado estuary in the winter). Again, the southeastward-moving stream - this time on the bottom - would be deflected to the right into a gyre according to the Coriolis effect (Figure 27-B, showing subsurface current flow in winter). As it moves out into the Gulf it would be expected to drop sediment and become warmed and diffused, gradually losing its density contrast. To complete the cell, the diffused water would swell upward and expand outward on the surface in a clockwise gyre of clear water and, where this reached the coasts and became chilled, there would be local areas of downwelling and offshore drift of bottom waters. Figures 27-C and 27-D show the winter flow in longitudinal and transverse sections, and Figure 27-A shows the postulated resultant surface flow from the upwelling center of that season's clockwise surface gyre.

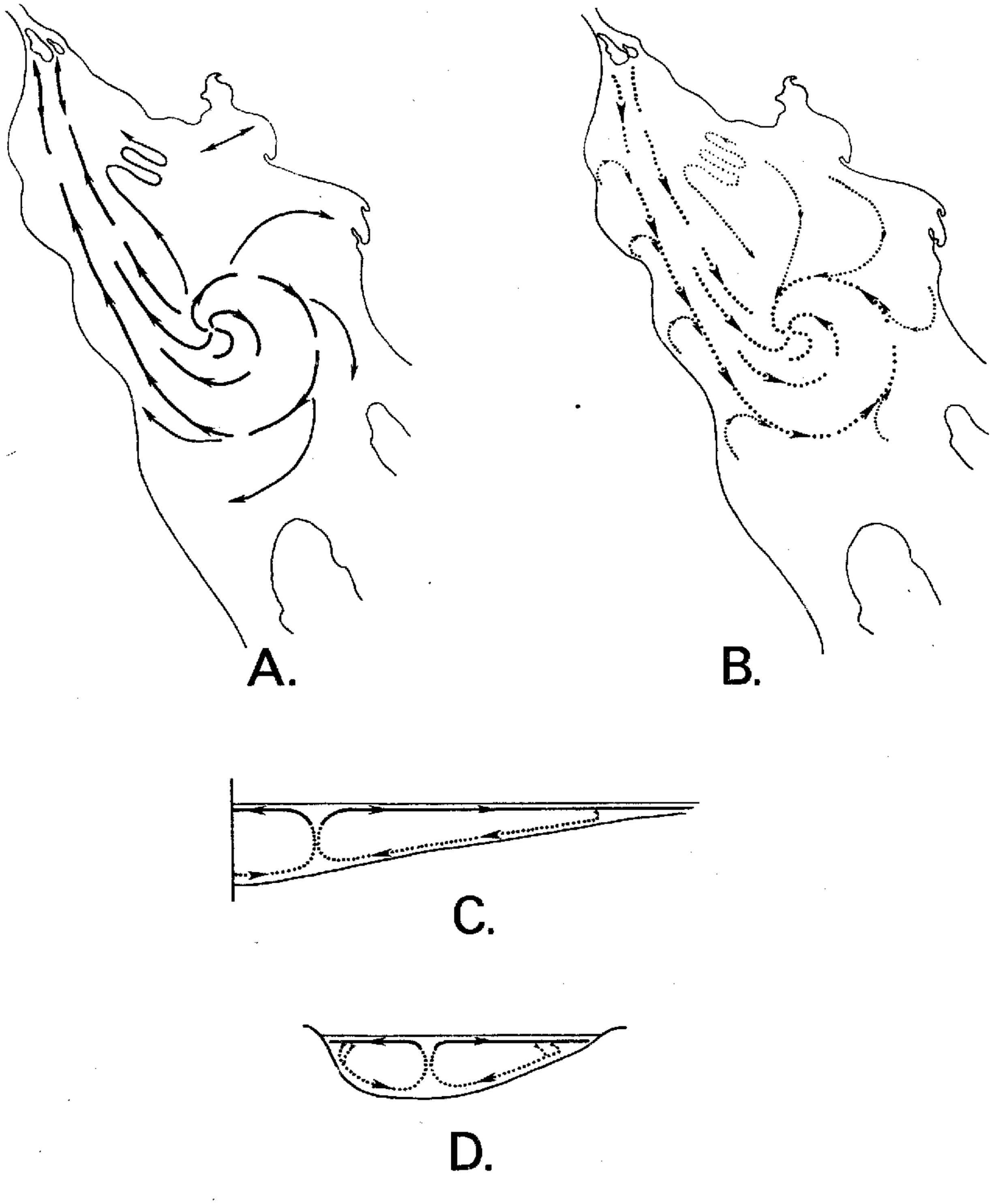


Figure 27. Thermal Dynamic Model, N. Gulf of California - Winter: A.- Surface Circulation; B.- Bottom Circulation; C.- N-S Section; D.- E-W Section.

4. Results of Data Analysis

a. Rotational Movement (Gyres)

Figures 28 and 29 show the summer counterclockwise gyres present on August 24th and September 11th of 1972, made visible by the high turbidity of the floating estuarine-derived layer. Note the cloud line in the September 11 image, indicating a probable temperature contrast at the edge of the gyre. These gyres are all cyclonic, converging upon a vortex which may be the downwelling portion of the summer convection cell according to the model previously described. We know that these gyres are surface patterns because they are seen with highest contrast in the two far red bands (6 and 7) which can be expected to produce images of only the top few centimeters of surface water (Figure 25). Further evidence of rotational movement also appears in section IV-4-d on tidal current velocities.

b. Upwelling Plumes

If the idealized summer convection cell of the model is considered in transverse (East-West) section, upwelling masses of cooler, clearer water would be expected along the coastlines (Figure 26). Figure 30 shows a plume of darker (clearer) water which would fit that expectation.

c. Internal Waves

During May, June, and July, the solar elevation angle exceeded 60 degrees above the horizon in the region of the northern Gulf, producing specular sun glint from the facets of surface waves having slopes exceeding 15 degrees. This effect obscured the visibility of the subsurface patterns of suspended sediments, but at the same time, produced patterns of surface wave roughness in the images. Cyclically banded patterns with wave lengths of from 2 to 5 kilometers are seen in images in all four of the spectral channels and are presumed to be bands of slicks generated by divergent zones above the crests of internal waves. We hypothesize that these internal waves are formed on the interface under the thin, buoyant estuarine layers of warmer water described in the summer convection model. Figure 31 shows two types of internal wave patterns: adjacent and parallel to the west coast of the northern Gulf, one set appears to occur within a single long mass of estuarine water which eventually curls into a gyre at its southern end in this image. The other type of internal wave pattern in this scene occurs in the mid-Gulf as overlapping arcuate sets concave to the west, which may be remnants of older estuarine gyres of previous tidal pulses that have drifted eastward. The fact that these banded wave patterns end abruptly in mid-Gulf is taken as evidence that these are indeed internal wave patterns which are breaking against the edges of the floating lenses in which they are contained.

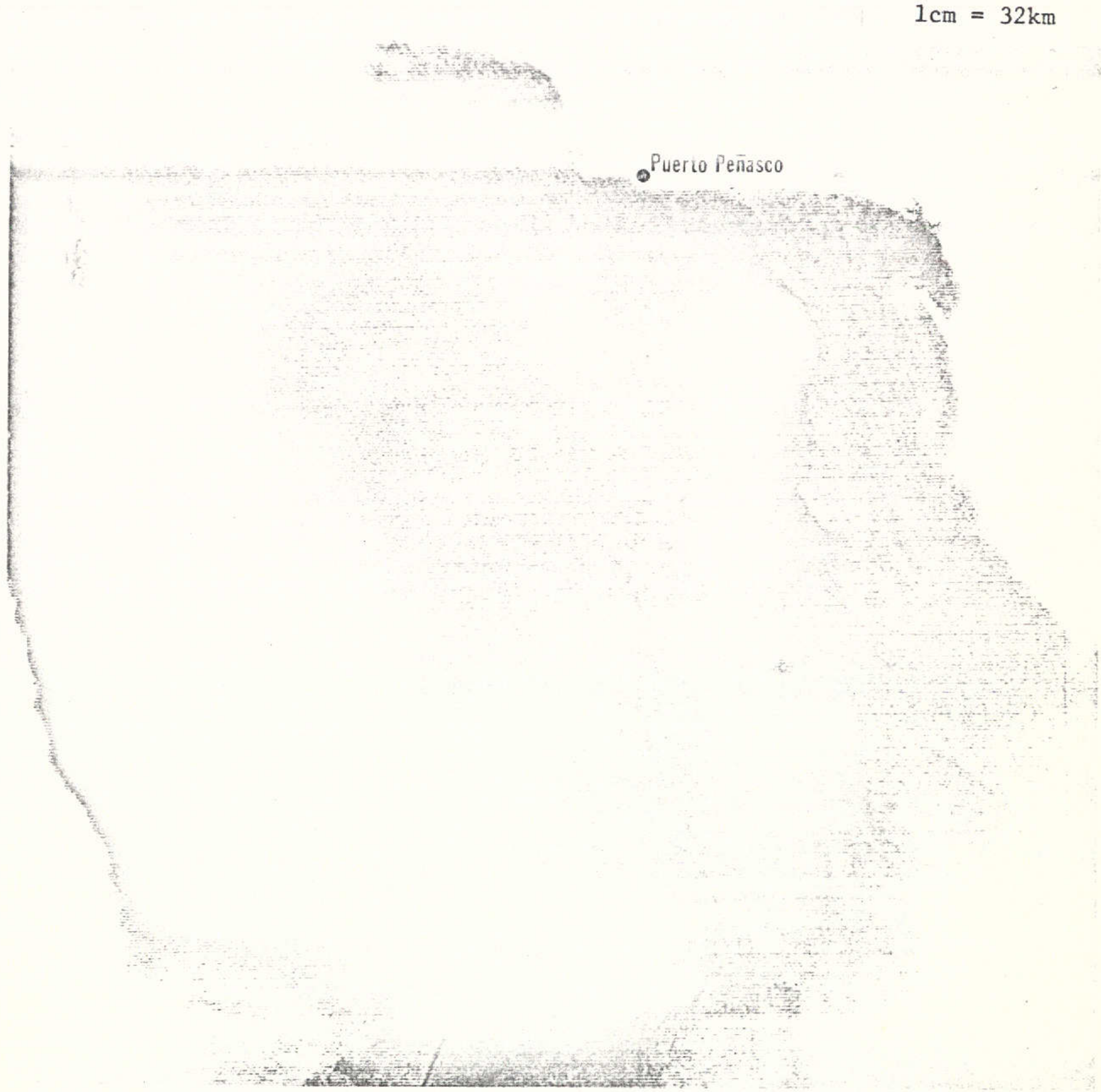
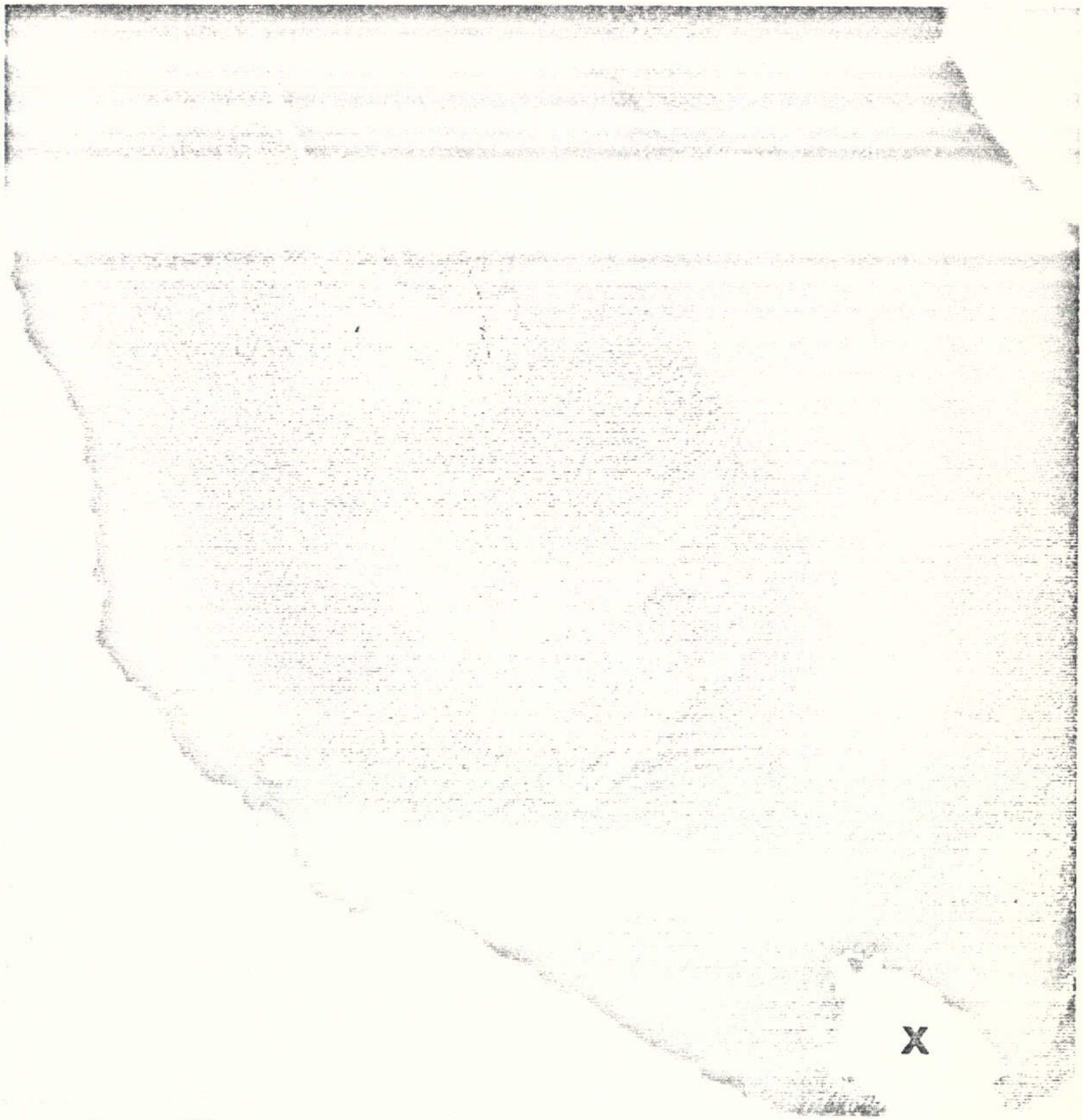


Figure 28. Turbidity Gyre, Northern Gulf of California (ERTS-1 Image 1032-17391-7) Aug. 24, 1972.

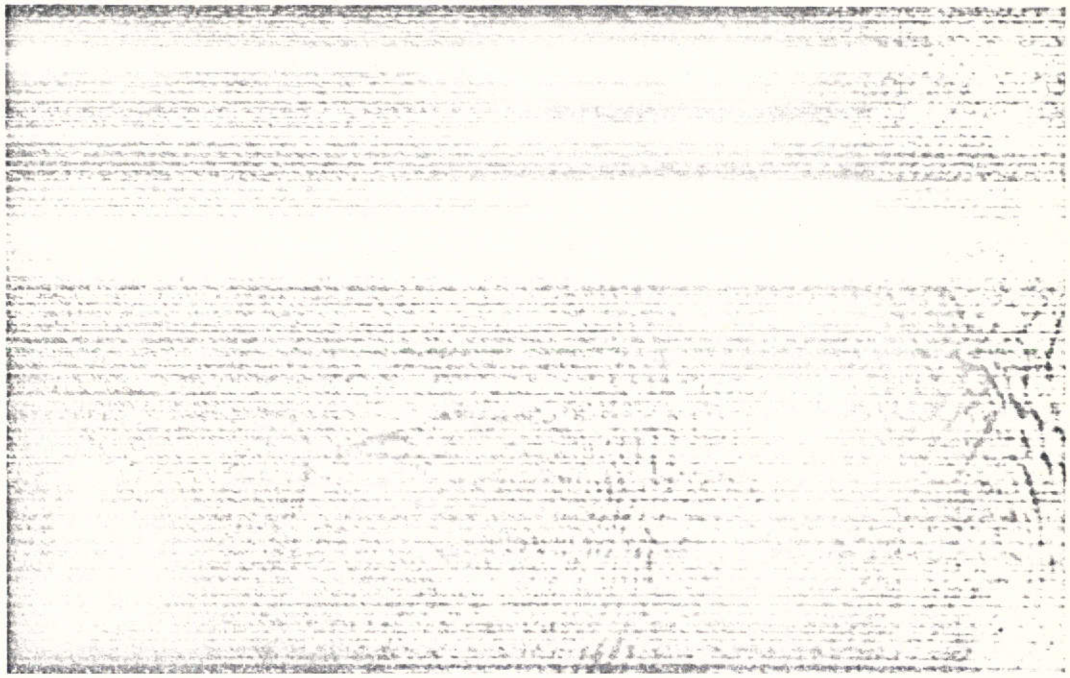


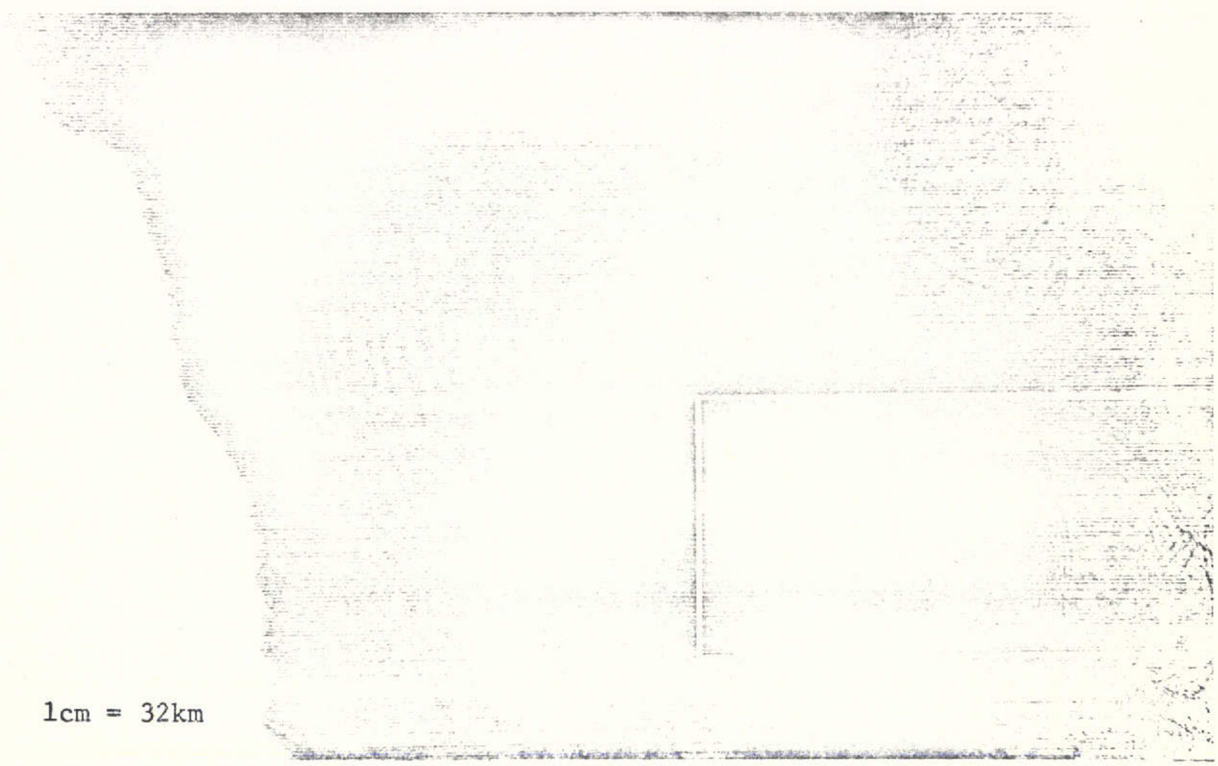
1cm = 32km

Figure 29. Turbidity Gyre in Northern Gulf of California. "X" marks Angel de la Guarda Island at bottom of image. (ERTS-1 Image 1050-17392-7) Sept. 11, 1972.

1cm = 32km

Figure 30. Plume of Clear Water (near shore, upper right), Northern Gulf of California. (ERTS-1 Image 1069-17443-5)





1cm = 32km

Figure 31. Internal Waves, Northern Gulf of California. Image of area just north of Angel de la Guarda Island; Baja California coast on left. Upper photo is enlargement of area indicated by white frame on lower photo. (ERTS-1 Image 1302-17401-7)

At the bottom of Figure 31 where an incoming tidal jet is flowing northward between Isla la Guarda and the Baja California coast, the edge of the tidal current is delineated by the sheering of the internal wave patterns. Figure 32, from the same frame, shows an hourglass-shaped white blotch about 9 kilometers in length which is difficult to explain. Fog banks would not be expected at this time of year in the Gulf. This pattern might be turbulent white water caused by the breaking of unstable internal waves at the surface. Patches of rough white water occurring during clear, calm weather have been reported by aviators and boatmen (personal communication with John R. Sumner, University of Arizona).

d. Tidal Current Velocity

Figures 33 and 34 (4 and 5 November, 1972) show a turbidity banding pattern which is a historical record of the diurnal tidal pulses. The width of the bands varies from approximately 5 nautical miles in the northeast along the Sonoran coast to 20 miles in the southwest along the Baja California coast, giving average net velocities of 0.4 and 1.7 knots, respectively. These velocities represent the direct measurement of the long-term component upon which the tidal components are superimposed. The differential in velocity on the two sides of the Gulf illustrates a counterclockwise rotary component of net velocity. This agrees with the expected diversion of flow to the right towards the east from the Coriolis effect on this outward convective flow.

e. Tidal Phases

The question of tidal phase velocity in the extreme northern part of the Gulf of California has not been completely resolved (J. B. Matthews, in D. A. Thomson, 1969). New information for measuring tidal phase velocity is available in the ERTS-1 imagery. Figure 35 is a photograph of a composite sandwich overlay consisting of a positive 70 mm. transparency of band 7, May 21, 1973 (1302-17394) over a negative 70 mm. transparency of band 7, June 8, 1973 (1320-17393). This shows only the intertidal zone. A tidal calendar (Thomson, 1973) is available for Puerto Peñasco, which town is located about 1/3rd of the frame from the right side of this 180-kilometer image. According to the calendar,.on May 21 the tide was at 0 ft. (low tide), and on June 8 the tide was at 10 ft. (high tide); the wind was approximately 4 knots from the southeast on both dates. Correct use of satellite synoptic imagery in this and other ways should allow measurement of tidal velocities in this region where access with sophisticated instrumentation for direct measurement is difficult. Unfortunately, it appears that we will not be able to record both extremes of the 20-plus foot vertical excursions of spring tides in the northern Gulf with ERTS-1 data because the times of imagery overpasses do not coincide with the peaks of the spring tides.

Figure 36 (May 21, 1972, band 7) was taken during a low point of spring tides. A 17-foot intertidal zone is recognizable by its distinct dark gray tone. Determinations of the total area of the exposed zone would be a relatively

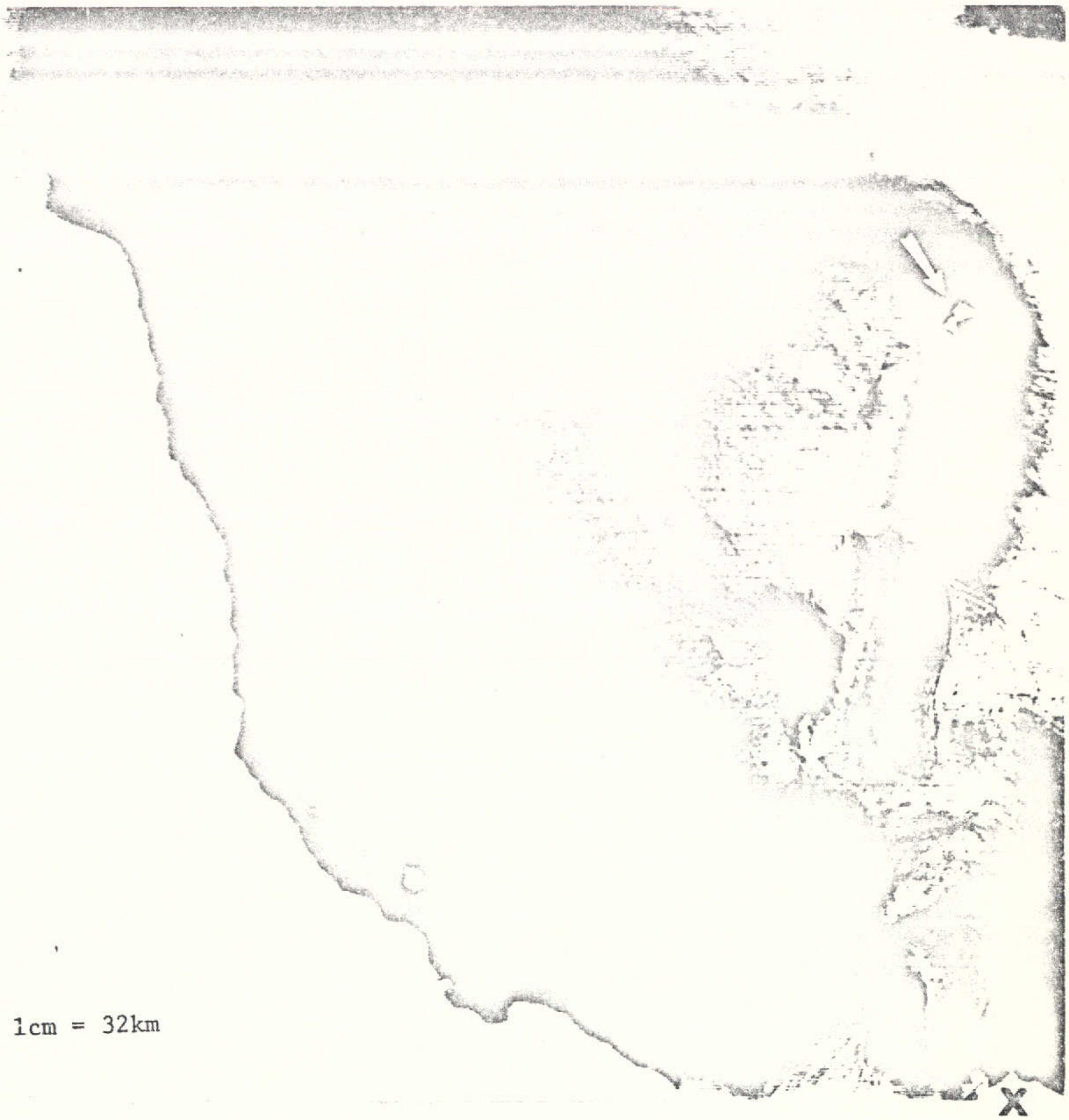


Figure 32. Unexplained Hourglass-Shaped Figure (Turbulent White Water??), Northern Gulf of California. Extreme northern tip of Isla Angel de la Guarda indicated by "X" at bottom of photo. (ERTS-1 Image 1284-17402-7)

1cm = 32km

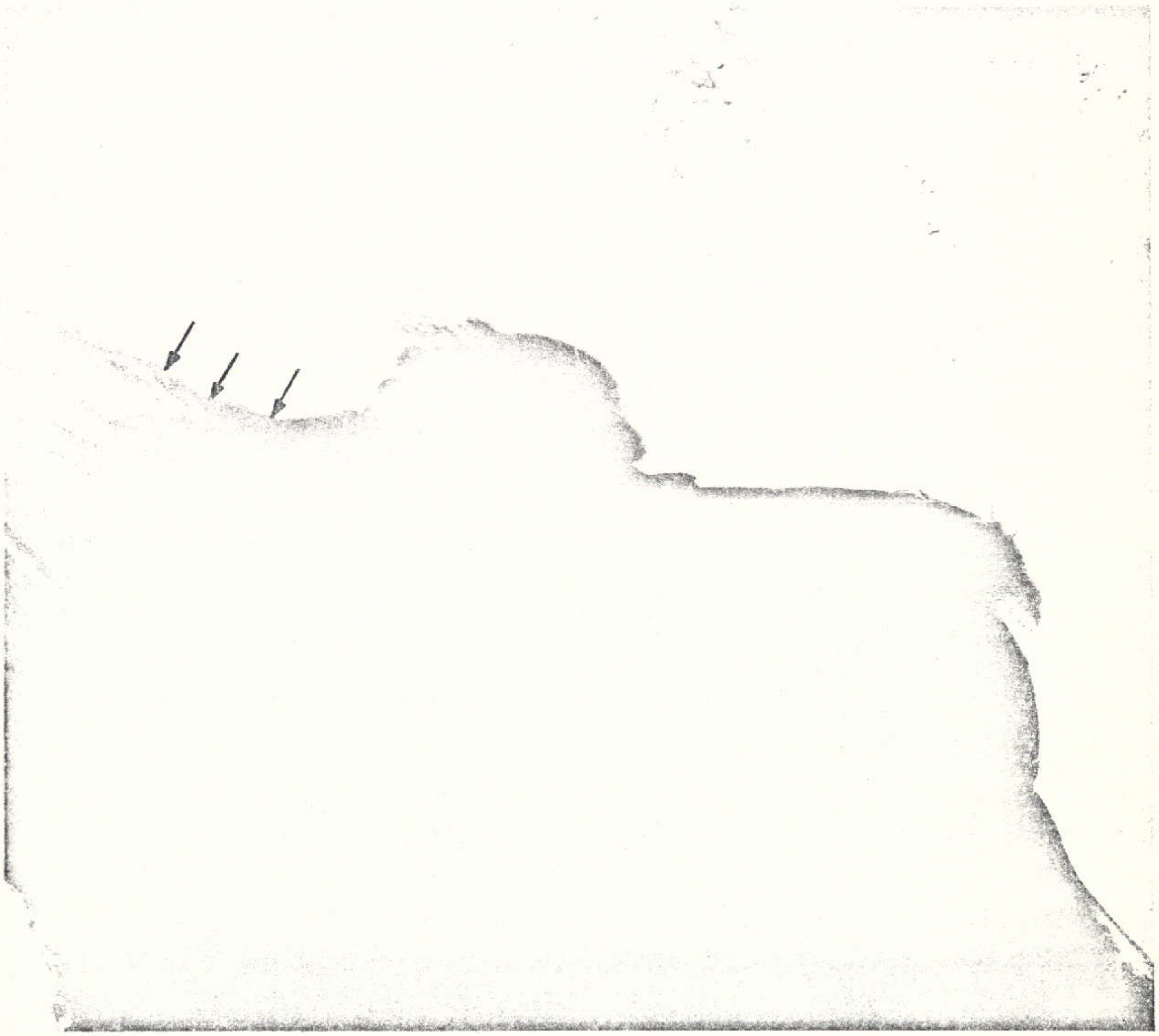


Figure 33. Turbidity Banding Demonstrating Tidal Pulses, Northern Gulf of California. Location of Puerto Penasco may be determined by comparing with Fig. 28. (ERTS-1 Image 1104-17393-5)

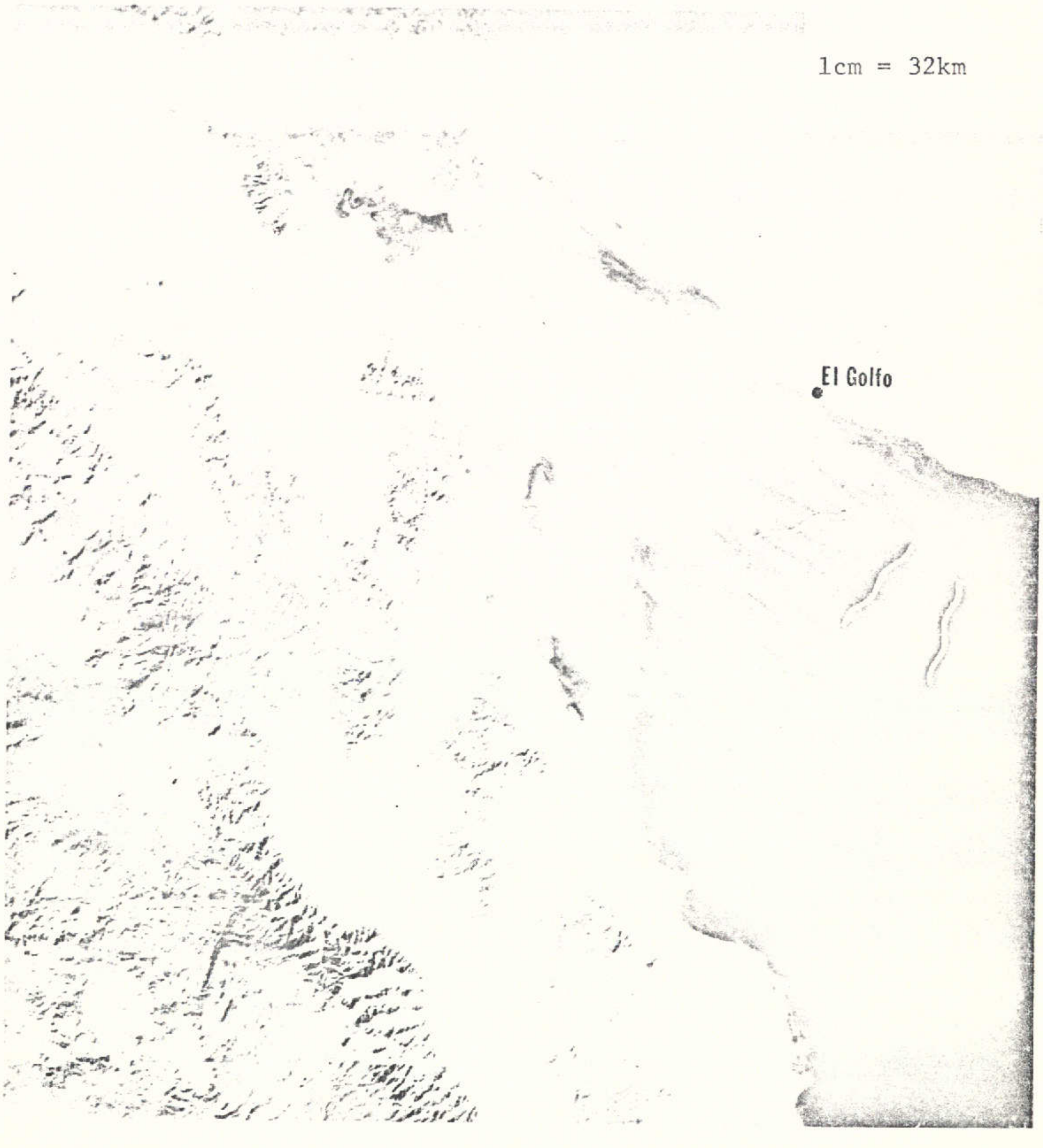


Figure 34. Turbidity Banding Demonstrating Tidal Pulses, Northern Gulf of California. Photo of Colorado River mouth. (ERTS-1 Image 1105-17452-5)

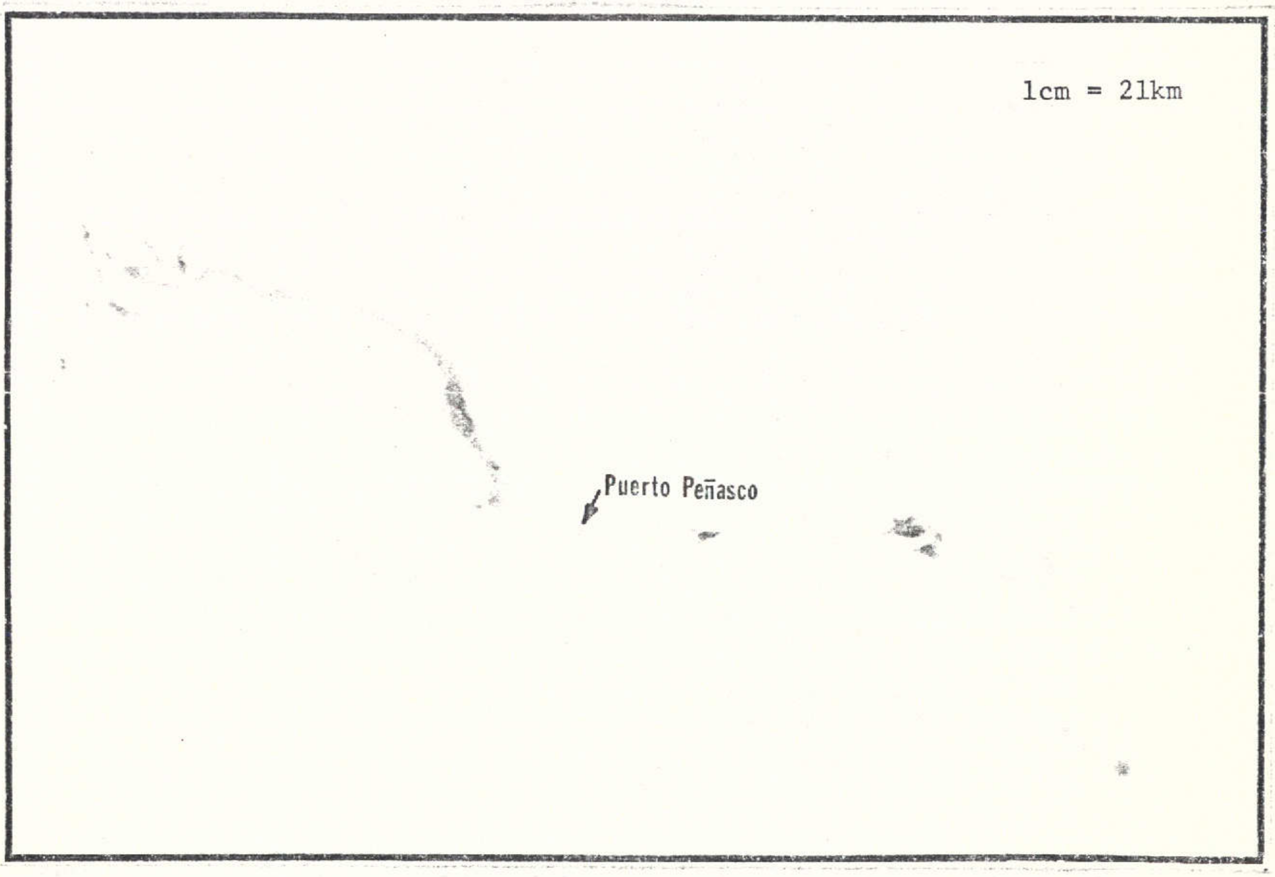


Figure 35. Positive-Negative Sandwich Showing Intertidal Zone, Northern Gulf of California. (ERTS-1 Images 1302-17394-7 and 1320-17393-7)

Figure 36. Intertidal Zone, Northern Gulf of California. Location of Puerto Penasco may be determined by comparing with Fig. 28. (ERTS-1 Image 1302-17394-7)

simple task, using the ARETS program's videoscanning densitometer. By way of demonstrating an immediate practical application of this type of data, there are extensive commercial clam beds in the northern Gulf. These are restricted to particular portions of the intertidal zone on mud flats. Estimations of the total producing area should be of utility in managing the resource.

f. Runoff

On the imagery for March 10, 1972 we have tentatively identified a floating sheet of rain water made visible by the slight increase in surface turbidity, a cloud line indicating a temperature step at the boundary of the turbid layer, and on-shore evidence of rain in the area (no rain recorded at the Puerto Penasco marine station, however). Figures 37 A, B, and C show pairs of images from February 20, March 10, and March 28, 1972 in which band 7 images were enhanced for a) land and b) water, respectively. These sequential images show: 1) cloudy weather previous to March 10; 2) the presence of the runoff layer at sea on March 10; and 3) the absence of this layer by March 28. Also, compare the high albedo of the adjacent desert area shown in the March 28 image with the dark tones of the moist soil in the March 10 image.

g. Wind effects upon surface layers

Wind-induced drift of the warmer surface layers are evident when meteorological data is compared with the imagery. For example, in Figures 38 and 39 of August 24 and 25, 1972, a 12.2 knot southwest wind has pushed the cyclonic surface gyre and other turbid surface layers northeasterly whereas the multispectral quadrant of Figure 40 (12 Sept. '72), shows the estuarine surface layer plastered against the western shore by a 3.5 knot northeasterly wind.

h. Orographic indicator of a shoal

Hydrographic charts of the Gulf indicate a subsurface shoal at latitude 31° 20' N. and longitude 114° 35' W. In Figure 41 a disturbance of incoming laminar tidal flow water shows as plume where it appears that the estuarine layer has been torn by a subsurface protrusion. The point of the plume coincides with the mapped location of the shoal.

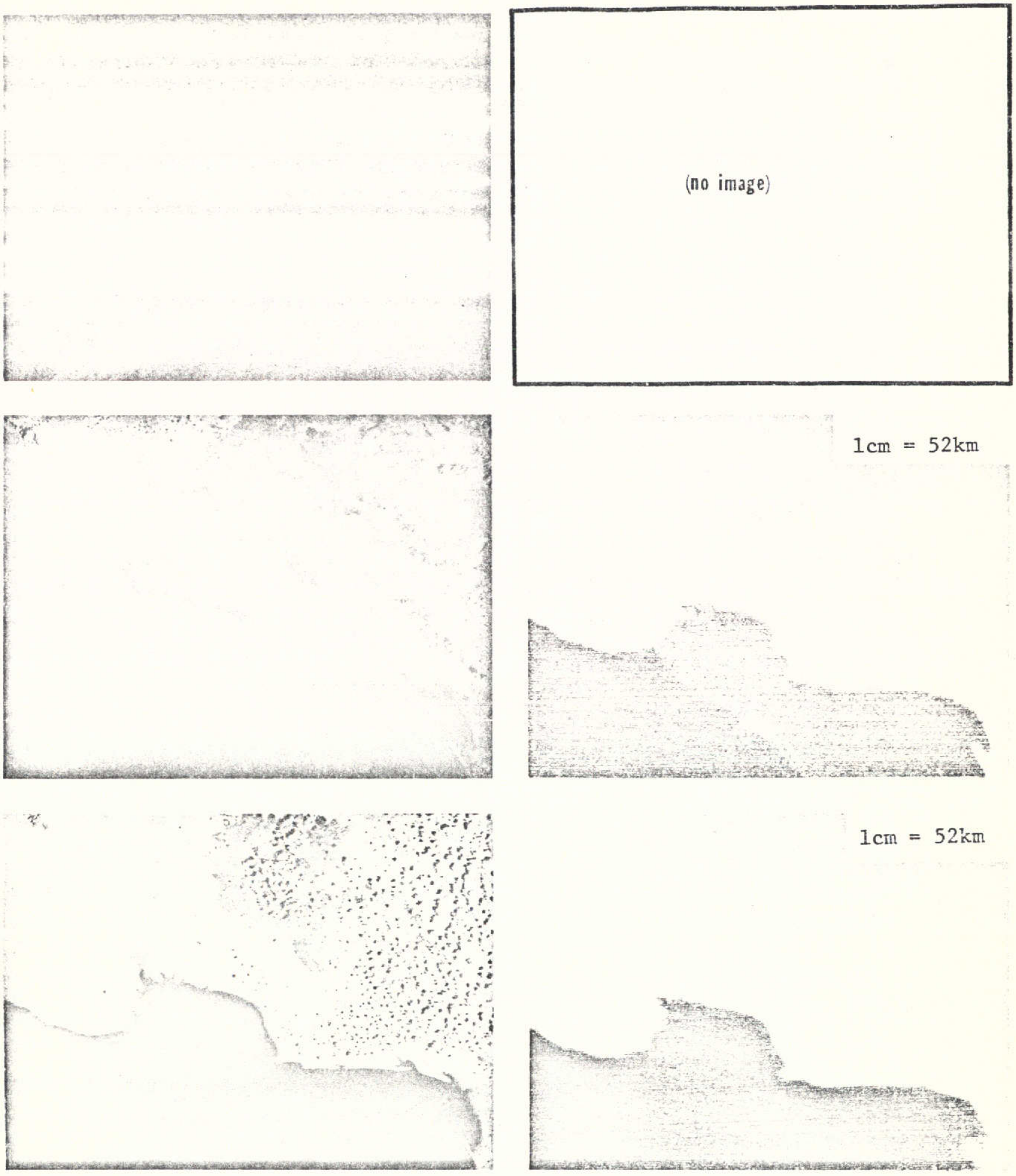


Figure 37. History of Rainfall and Runoff, Northern Gulf of California. Location of Puerto Penasco may be determined by comparison with Figure 28. Figures on right enhanced for water; figures on left enhanced for land. A-Feb. 20, cloudy weather (ERTS-1 image 1212-17401-7); B-Mar. 10, runoff layer at sea, low albedo of moist desert soil (ERTS-1 image 1230-17400-7); C-Mar. 28, runoff layer gone, high albedo of dried-out desert soil (ERTS-1 image 1248-17400-7)

1cm = 32km

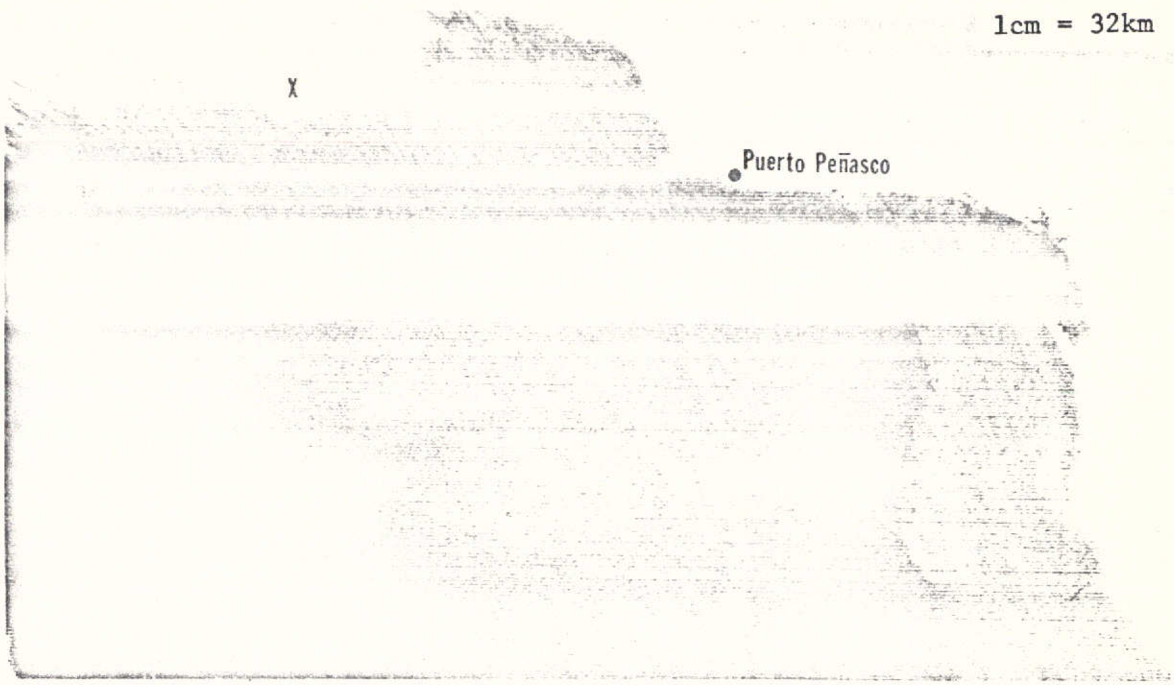


Figure 38. Wind Effects on Surface Layers, Northern Gulf of California. Southerly wind pushing turbidity gyre toward NE coast; "X" mark identical with that on Fig. 39 of following day. (ERTS-1 Image 1032-17391-7).

1cm = 32km

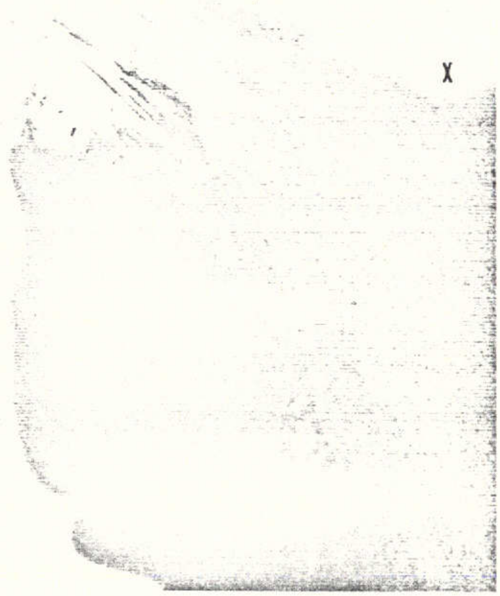


Figure 39. Wind Effects on Surface Layers, Northern Gulf of California. Southerly wind pushing surface waters toward NE coast; "X" mark identical with that on Fig. 38 of preceding day. (ERTS-1 Image 1033-17444-7).

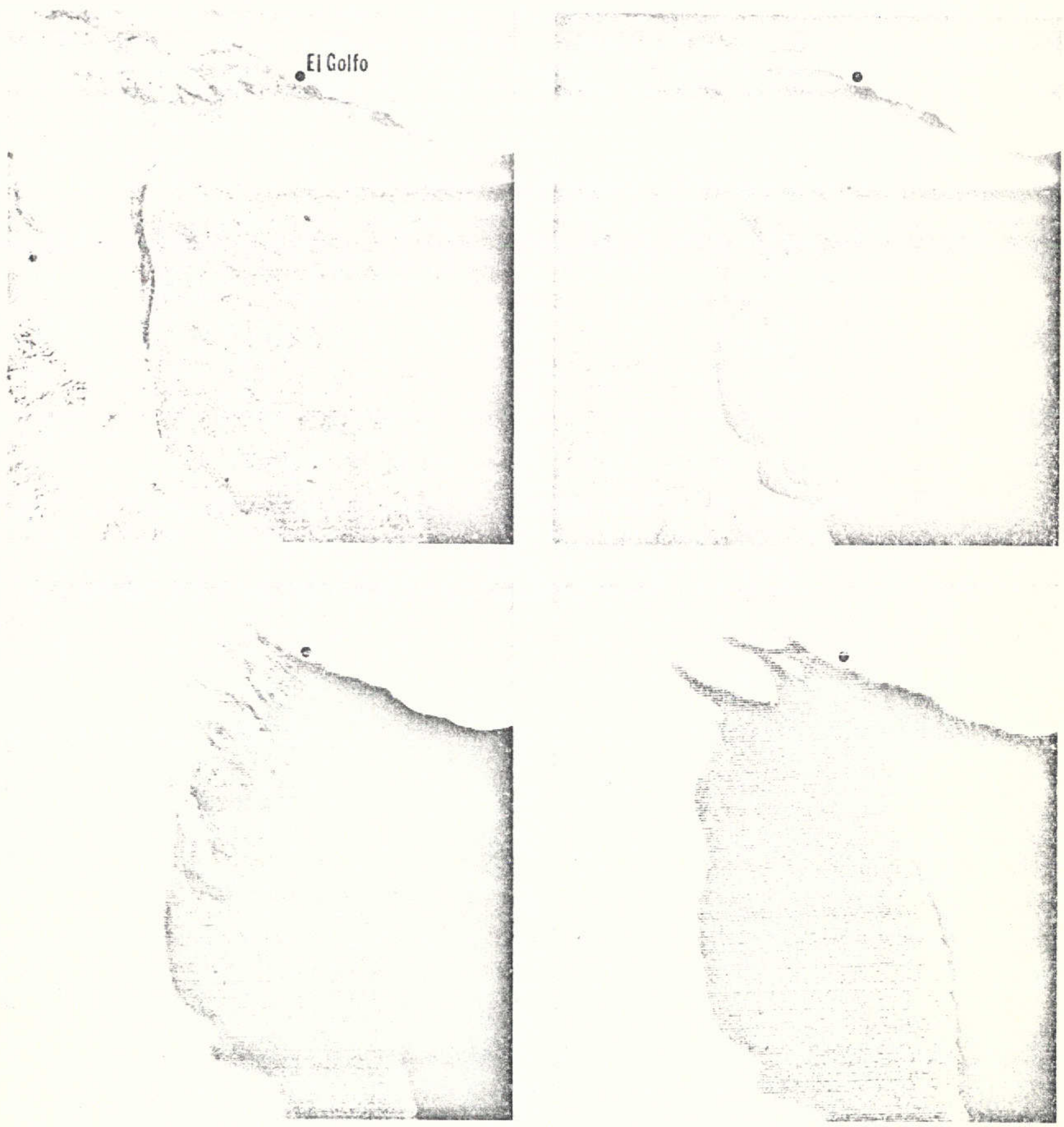


Figure 40. Wind Effects on Surface Layers, Northern Gulf of California. Mouth of Colorado River at upper left. Upper left image, Band 4; upper right, Band 5; lower left, Band 6; lower right, Band 7. Strong northeasterly wind pushing surface layers against W. shore. (ERTS-1 Image 1051-17443-4,5,6,7)

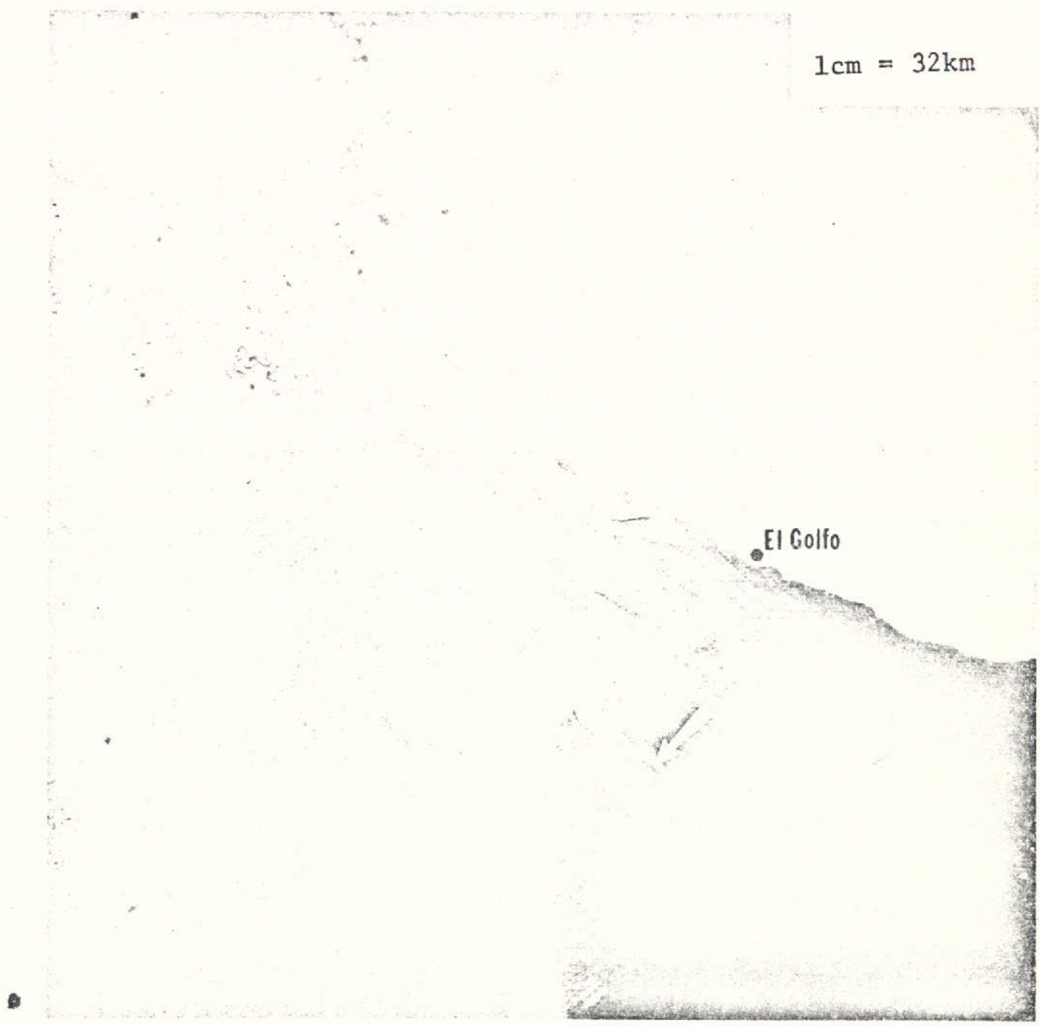


Figure 41. Orographic Indication of a Shoal, Northern Gulf of California. (ERTS-1 Image 1015-17442-6)

V. NEW TECHNOLOGY

1. Buoy Design

The concept of using poured concrete around formed plastic is believed to be a novel idea in its application to moored, instrumented buoys. Conventional instrumented buoys are of welded steel and are significantly more expensive than the design herein described. We think of our buoys as "poor man's buoys" which can be constructed by almost any group for their own use without resorting to specialist subcontracts. Ferro-concrete vessels are well known, of course, but a conventional hollow concrete hull is generally much thinner and contains vastly more steel. The design illustrated in Figure 6 is made by pouring a very fluid mix of rich concrete into plywood forms around a pre-placed core of poly-urethane and pre-placed reinforcing steel which consists of rectangular mesh wire of the type commonly used in concrete floors plus a loop of round reinforcing rod on each side, projecting through the surface of the concrete at each end to provide attachment points for anchor cables.

Another novel feature is the provision of a steel-lidded central well in which are placed fiberglas-plastic boxes housing instrumentation, electronics, and batteries. This arrangement ensures temperatures close to ambient sea water, protects the vulnerable gear from external damage including vandalism (even rifle bullets from passing boats, which is not an uncommon occurrence) and still permits servicing by replacement of individual packages.

The cost of materials and construction labor for the buoy described here was under $1,000 (not including cost of engineering supervision or of the re-usable forms). The cost of the fiberglas boxes, sealing and mounting hardware will vary with the design and number of boxes used, but will be between $1,000 and $2,000 for materials and labor.

Still another novel feature of the design is the method of accommodating anchorage in currents up to 10 knots. In most buoys the downward component of anchor cable force becomes so large in currents of the order of 10 knots that the buoy completely submerges. In practice, it becomes difficult to provide enough buoyancy to prevent this from happening since increasing the volume to improve buoyancy also increases drag, so one only gains slowly at the expense of considerable dollar cost. In the current design, the buoy is made in a shape which produces aerodynamic lift and the cable is attached at a point which allows the structure to assume a positive angle of attack relative to the current. This lift, of course, generates drag, but since a value of L/D considerably greater than 1.0 is readily obtainable, the buoyancy is significantly augmented by lift in strong currents. This feature has been partially tested by the observation that, under tow at approximately 4 knots, the buoy assumed a very definite, stable positive angle of attack, thus qualitatively confirming that the cable attachment points were correctly chosen.

2. Electronics

In section II-2-c a technique is described for eliminating noise from the slow speed multiplex circuitry by locking out input for a pre-determined time. Although we rate this an unremarkable approach to the problem, which may well have been used previously, we do not find mention of it in the literature.

3. Imagery Analysis

While the optical properties of water are well known, and the decreasing depth of penetration with increasing wave lengths of the four MSS channels is widely understood, we are not aware of previous applications of this as a sounding device. Accommodating for the fact that this sequential penetration phenomenon breaks down in very turbid waters, where the red band, number 5, may be expected to have maximum penetration, we are experiencing a degree of success in the mapping of subsurface turbidity layers by satellite imagery.

The use of sun glint patterns, which normally imply unwelcome loss of data, to detect internal wave patterns through their modification of surface water roughness is, so far as we are aware, a new application.

VI. CONCLUSIONS

A. Remote, Instrumented Buoy

1. The concept of a "Poor Man's Buoy" of concrete-encased plastic foam, built at low cost with simple tools, is promising. Actual buoy construction should begin only after all electronics are completely assembled and boxed, in order that design of forms may be accommodated to payload in ideal fashion. All deck structures and anchoring rigs should be designed with a safety factor of the order of 10. Electronic unit boxes should weigh 50 pounds or less, for safe handling at sea.

2. Automatic satellite telemetry equipment for marine applications can be constructed by the electronics shop of any major university without insurmountable problems. Systems can be designed for dependable operation for periods of up to a month at a time between servicing visits.

3. Buoy-telemetered data should be backed up by on-buoy recording of data, despite the relatively high transmission rate via satellite passes (14 to 18 usable passes per day).

4. Buoy data from critical sites would be of enormous value in supplementing ship-collected data on periodic cruises, in that diurnal phenomena and rapidly-changing major fronts could be monitored to supplement the wide-ranging, but temporally infrequent ship data for accurate interpretation of the dynamic environment.

5. For the northern Gulf of California, 5 buoys would be required for ideal monitoring: 1 each in Bahia San Jorge and Bahia de Adair, 1 in the Delta station subgroup, and 1 in the shore station area off Punta Borrascoso; the fifth buoy would be moved about as data needs became apparent. The latter buoy would also be used for monitoring sea stations, if anchoring problems proved capable of solution, and would be used for periods of semi-attended drift. The shallow shelf conditions north of San Felipe and the large tidal range of the area indicate against establishing a permanent monitoring buoy there.

B. Gulf of California Surface Oceanography

1. Baseline information was established for the monitoring of seasonal changes in the northern Gulf of California by high-altitude flights and satellites.

   a) The seasonal fluctuations of salinity, temperature, and turbidity were measured and related to what historical data exists. Comparability of recent data with historical data

demonstrates relatively constant norms and cycles, without conspicuous drift over time.

b) Turbidity is one of the least understood and most important physical parameters of the northern Gulf. It is also the single most useful tool for deriving a wide variety of information on other parameters through combination of direct measurement with satellite imagery. It is probable that the turbidity regime will prove to be the principal environmental factor controlling the distribution and abundance of plankton and nekton in the northern Gulf.

2. A predictive model for the circulation patterns of northern Gulf waters can be (has been) formulated on the basis of satellite imagery backed by surface truth data. This model seems to explain a complex series of phenomena which previously appeared to be unrelated or contradictory. The model is of a marine system created by terrestrial conditions (desert temperature regime); it should be considered as superimposed upon a more orthodox system of marine origin linked with southern Gulf waters, and not as a competing, exclusive explanation.

a) Near-surface physical oceanographic measurements made during the winter months corroborate the above model with respect to the "winter-subsurface" circulation system. Predicted "winter-surface" phenomena are not apparent in actual measurements, presumably because: 1) gyre centers would be too well-defined to appear as other than point anomalies in a station mosaic; 2) the predicted layer of clear water at the surface is probably of decreasing thickness northward, and probably not detectable without a continuous turbidity monitor which could be lowered through a water column for continuous readings; the same layer is probably not detectable by normal oceanographic instruments measuring salinity and temperature due to its surficial nature; 3) the surface layer is actively moved about by winds and disturbed by waves, so that its integrity and position would vary markedly during the period of each cruise.

b) Insufficient data from summer season cruises (due to contract limitations) prevent conclusions as to whether surface data corroborate or refute predictions of the above model.

C. Imagery Analysis

A. The northern Gulf of California is an optimal area for experimental oceanographic studies by satellite. Visibility there is superior to that of almost any other marine area within convenient reach of major U. S. technological centers. The wide excursions of many environmental parameters (tides, temperature, turbidity, salinity, etc.) in the northern Gulf provide a selection of "magnified" variables which are ideal for experimentation.

B. Given adequate comparison data from ground observations, it is difficult to predict the limits of what can be learned by satellite sensor monitoring in the northern Gulf. Section IV of this report details a number of examples of practical information gained, much of which would likely have remained undetected without the synoptic imagery possible from satellites. Among these are:
   1. short, internal waves
   2. measurement of surface current velocity
   3. location of upwelling plumes
   4. demonstration of mobility of wind-driven surface layers
   5. demonstration of gyres and other dynamic phenomena too complex and too transient to map with point data.

C. Through appropriate interpretation of satellite imagery now in hand, new and more dependable bases are available for Mexican decisions on such matters as:
   1. impact of nuclear plants on fisheries
   2. sewage disposal problems of tourist beach developments
   3. management of commercial clam beds
   4. management of catch levels, fishing seasons, and spawning preserves for commercial fishes in the extreme northern Gulf
   5. monitoring sites for suspected pesticide and heavy metal contamination
   6. siting of mariculture activities in the northern Gulf.

D. A number of distinctive features in the northern Gulf, identified in this program, are worthy of further study. Among these are: possible sites of submarine springs at intersections of major fault lines; traceable plumes of freshwater runoff from the Sonoran shore; alternating (and probably shifting) systems of ridges and channels in the Delta region; complex patterns of internal waves and suspected surface agitation.

VII. RECOMMENDATIONS FOR FUTURE ACTION

General

All investigators contemplating projects in the Gulf of California, which is for all intents and purposes a private, territorial sea of the Republic of Mexico in its northern portion, should give first priority to establishing contact with one or more Mexican institutions as potential cooperating partners. A formal request for permission to work in the area is required, and this should be put forward at the highest possible level, through the U.S. Embassy in Mexico City. The request should outline precise activities which are contemplated,and should detail the share of work and responsibility to be undertaken by named Mexican scientists. Insofar as possible, Mexican-registered ships should be used to simplify problems of sailing orders, port entry, etc.

Remote Oceanographic Data Collection Buoy

1. Use of the design presented here for oceanographic buoys should be evaluated with regard to the amount of stability and splash-free conditions required. The present low structure has some advantages (such as minimal wind drag) but our own mechanical engineers felt that a second generation design should provide for more freeboard. In addition, the buoy has substantial motion even in relatively calm seas which removes or restricts on-buoy repair and installation capabilities.

2. All buoy instrumentation should be restricted to DC power requirements-- no sensors requiring 110V AC should be considered for remote buoy installation. All integrated circuit components should be of the C-MOS type, or of comparable low level power consumption. Connectors should be capable of either straight or right-angle lead-off.

3. A minimum of six months' lead time should be provided for selecting and ordering of electronics. If significant design and assembling requirements are present, perhaps even more time should be allocated. Work should be organized in a parallel rather than in a strict serial fashion, with at least 6 skilled technicians assigned to the project for a buoy such as was built for this program. Provision should be made for in-sea testing, failure, emergency repair, etc., in both time and financial planning.

4. NASA should tie contract suppliers of DCS units and Field Test Sets to guaranteed servicing contracts for units supplied to a wide variety of investigators with varying plans for use of the equipment.

5. It became evident that anyone considering a buoy telemetering system should install an on-buoy data recording system and should not rely on transmission of data as their sole recovery means. As was demonstrated in our project,

the antenna is the weak link and an operating non-transmitting buoy is useless unless an alternate means is provided for recovery of the data. This takes on increasing importance with increasing difficulty of accession to the site of deployment.

6. A continued program of developing satellite-linked, remote-operating marine sensors should be carried out. There is increasing need for this sort of gear to solve pressing problems, and the cost-benefit ratio of such buoys will probably be superior to that of other approaches.

Biological Studies and Surface Oceanography

1. The seasonal analyses of temperature, salinity and turbidity presented in section III-7 suggest that the northern Gulf of California is a complex of environments containing a mosaic of localities characterized by seasonal gradients in temperature, salinity and turbidity. This was especially apparent with respect to the seasonal curves of air temperature. The suggestion that the biota may be characterized as belonging to habitats of Sea, Delta or Shore seasonal types could be investigated with the data presented in this report.

2. The channel which extends northward from Wagner Basin should be mapped and the associated spatial and seasonal current structure should be investigated. Our conclusions indicate that a minimum of two cruises, one during winter and one in summer, would be required to establish the function of this channel as a principal circulatory pathway for the northern Gulf of California.

3. Future oceanographic investigations in the northern Gulf of California, especially those which propose to sample the Delta area, should plan to include <u>in situ</u> measurements of specific gravity. The use of hydrometers ought to be considered as those would measure the total value, including the seston contribution.

4. Due to the large magnitude of the tidal excursion in the northern Gulf of California, surface truth transects should be acquired over a distance of 150 km within a total time of about two hours. These should include spectral radiometric readings for calibrating multispectral imagery, which are obtained from sufficient height above the water surface to obtain an integration of the specular flashes from surface waves. The most practical and economical means of meeting these two requirements is the use of aircraft. Since the northern Gulf of California is frequently calm with winds of only 4 knots, light aircraft could be used for rapid ocean surface sampling. A seaplane or float plane can carry continuously recording optical and thermal radiometers such as that recently available at the University of Arizona, Department of Arid Lands Studies. Mexican or U.S. commercial aircraft could be chartered for this purpose.

Image Processing

Our correlation of spectral properties to various surface-identified water types indicate that computer mapping from the ERTS-1 MSS digital tapes will be possible. We suggest that computer processing of spectral data will yield a classification of water bodies not only by their turbidity, but by their degree and type of stratification -- clear water overlying turbid water, turbid over clear, etc. ERTS-1 MSS tapes of the northern Gulf of California have been obtained for this purpose.

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Appendix A

STANDARD OCEANOGRAPHIC DATA FORMS USED IN NASA PROJECT UN603 --

STUDY OF THE MARINE ENVIRONMENT OF THE

NORTHERN GULF OF CALIFORNIA

Cruise Report Sheet 1.

FILED BY ______________________ **PROJECT SUMMARY SHEET** DATE ______________

PROJECT NO.

PROJECT TITLE

VESSEL

INCLUSIVE DATES

DESCRIPTION OF PURPOSE & AREA SAMPLED

NO. OF STATIONS PLANNED

NO. OF STATIONS TAKEN

LIST OF STATIONS OMITTED

STATION MAP ATTACHED

STATION LIST ATTACHED

CHIEF SCIENTIST

CAPTAIN

OTHER SCIENTIFIC PERSONNEL

GENERAL REMARKS

PARAMETER	EQUIPMENT OR INSTRUMENTS	REMARKS

Cruise Report Sheet 2.

TYPE OF SAMPLE OR RECORD	STORAGE LOCATION	DISSEMINATED TO	COPY	ORIGINAL	DATE

TYPES OF ANALYSES, COMPUTATIONS, CALIBRATIONS	ANALYST	FILE LOCATION	DISSEMINATED TO	DATE

Cruise Report Sheet 3.

BIOLOGICAL SAMPLES

TYPE	ORIGINAL PRESERVATIVE	OTHER PROCESSING

Oceanographic Station Data Recording Form

Project No.	Station No.	lat.	sonar depth	wind	temp.	clouds	sea	swell	con. no.	weather
Vessel		long.		speed	dry	type	ht.	ht.		
Date	Time	navig.	Barometer	dir.	wet	amt.	dir.	dir.	visibility	

SALINITY-TEMPERATURE-CONDUCTIV.		Parameters	D1	D2	D3	D4	D5	D6
Instrument		conductiv.						
time in	wire angle	temperat.						
time up	wire angle	salinity						

OMEGA Computations	
LOP1 B-D reading	
St.1 PPC	
St.2 PPC (-)	
Tot. Correct.	
Corrected reading	
LOP2 C-D reading	
St.1 PPC	
St.2 PPC (-)	
Tot. Correct.	
Corrected reading	
Longitude	Latitude

CURRENT Instrument

Depth	X vector	Y vector	heading	speed	angle	direct
D1						
D2						
D3						

TURBIDITY
Instrument

wire length	Deck cell	X factor	sea cell
D1			
D2			
D3			
D4			
D5			
D6			

Secchi Disk reading

PLANKTON SAMPLING	sample 1	sample 2	sample3	sample 4	sample 5
wire length					
wire angle					
type					

OTHER SAMPLES (Specify)

COMMENTS

BOTTLE CASTS

no.	time	depth	angle	temp.	samp #	DO	PL	specify	specify	specify	specify

Time abandon station

Heading to next station

APPENDIX B

ERTS-1 IMAGERY ANALYZED FOR NASA PROJECT UN603

STUDY OF THE MARINE ENVIRONMENT OF THE NORTHERN GULF OF CALIFORNIA

Date	Frame ID Orbit No.	Time (GMT)	Bands	70 mm. pos.	70 mm. neg.	9.5" pos.
8/ 7/72	1015	17442	4,5,6,7	x	x	x
8/24/72	1032	17391	4,5,6,7	x	x	x
8/25/72	1033	17444	4,5,6,7	x	x	x
9/11/72	1050	17385	4,5,6,7	x	x	x
9/11/72	1050	17392	4,5,6,7	x	x	x
9/12/72	1051	17443	4,5,6,7	x	x	x
9/12/72	1051	17450	4,5,6,7	x	x	x
9/29/72	1068	17385	4,5,6,7	x	x	x
9/29/72	1068	17391	4,5,6,7	x	x	x
9/30/72	1069	17443	4,5,6,7	x	x	x
9/30/72	1069	17450	4,5,6,7	x	x	x
11/ 4/72	1104	17393	4,5,6,7	x	x	x
11/ 5/72	1105	17452	4,5,6,7	x	x	x
12/29/72	1159	17451	4,5,6,7	x	x	x
12/29/72	1159	17454	4,5,6,7	x	x	x
2/ 2/73	1194	17400	4,5,6,7	x	x	x
2/ 3/73	1195	17452	4,5,6,7	x	x	x
2/ 3/73	1195	17455	4,5,6,7	x	x	x
3/10/73	1230	17400	4,5,6,7	x	x	x
3/10/73	1230	17402	4,5,6,7	x	x	x
3/11/73	1231	17454	4,5,6,7	x	x	x
3/28/73	1248	17400	4,5,6,7	x	x	x
3/28/73	1248	17408	4,5,6,7	x	x	x
3/29/73	1249	17455	4,5,6,7	x	x	x
3/29/73	1249	17461	4,5,6,7	x	x	x
4/15/73	1266	17400	4,5,6,7	x	x	x
4/15/73	1266	17402	4,5,6,7	x	x	x
4/16/73	1267	17454	4,5,6,7	x	x	x
4/16/73	1267	17461	4,5,6,7	x	x	x
5/ 3/73	1284	17395	4,5,6,7	x	x	x
5/ 3/73	1284	17402	4,5,6,7	x	x	x
5/ 4/73	1285	17454	4,5,6,7	x	x	x
5/ 4/73	1285	17460	4,5,6,7	x	x	x
5/21/73	1302	17394	4,5,6,7	x	x	x
5/21/73	1302	17401	4,5,6,7	x	x	x
5/22/73	1303	17453	4,5,6,7	x	x	x
5/22/73	1303	17455	4,5,6,7	x	x	x
6/ 8/73	1320	17393	4,5,6,7	x	x	x
6/ 8/73	1320	17395	4,5,6,7	x	x	x
6/ 9/73	1321	17451	4,5,6,7	x	x	x
6/ 9/73	1321	17454	4,5,6,7	x	x	x
6/26/73	1338	17392	4,5,6,7	x	x	x
6/26/73	1338	17394	4,5,6,7	x	x	x
6/27/73	1339	17450	4,5,6,7	x	x	x
6/27/73	1339	17453	4,5,6,7	x	x	x
7/14/73	1356	17390	4,5,6,7	x	x	x
7/14/73	1356	17393	4,5,6,7	x	x	x
7/15/73	1357	17445	4,5,6,7	x	x	x
7/15/73	1357	17451	4,5,6,7	x	x	x

APPENDIX C

BIBLIOGRAPHY OF PERTINENT LITERATURE, NOT CITED IN REPORT FOR NASA PROJECT

UN603, STUDY OF THE MARINE ENVIRONMENT OF THE NORTHERN GULF OF CALIFORNIA

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APPENDIX D

Northern Gulf of California Place Names